MYP by Concept
4&5

Sciences

Paul Morris
Radia Chibani
El Kahina Meziane
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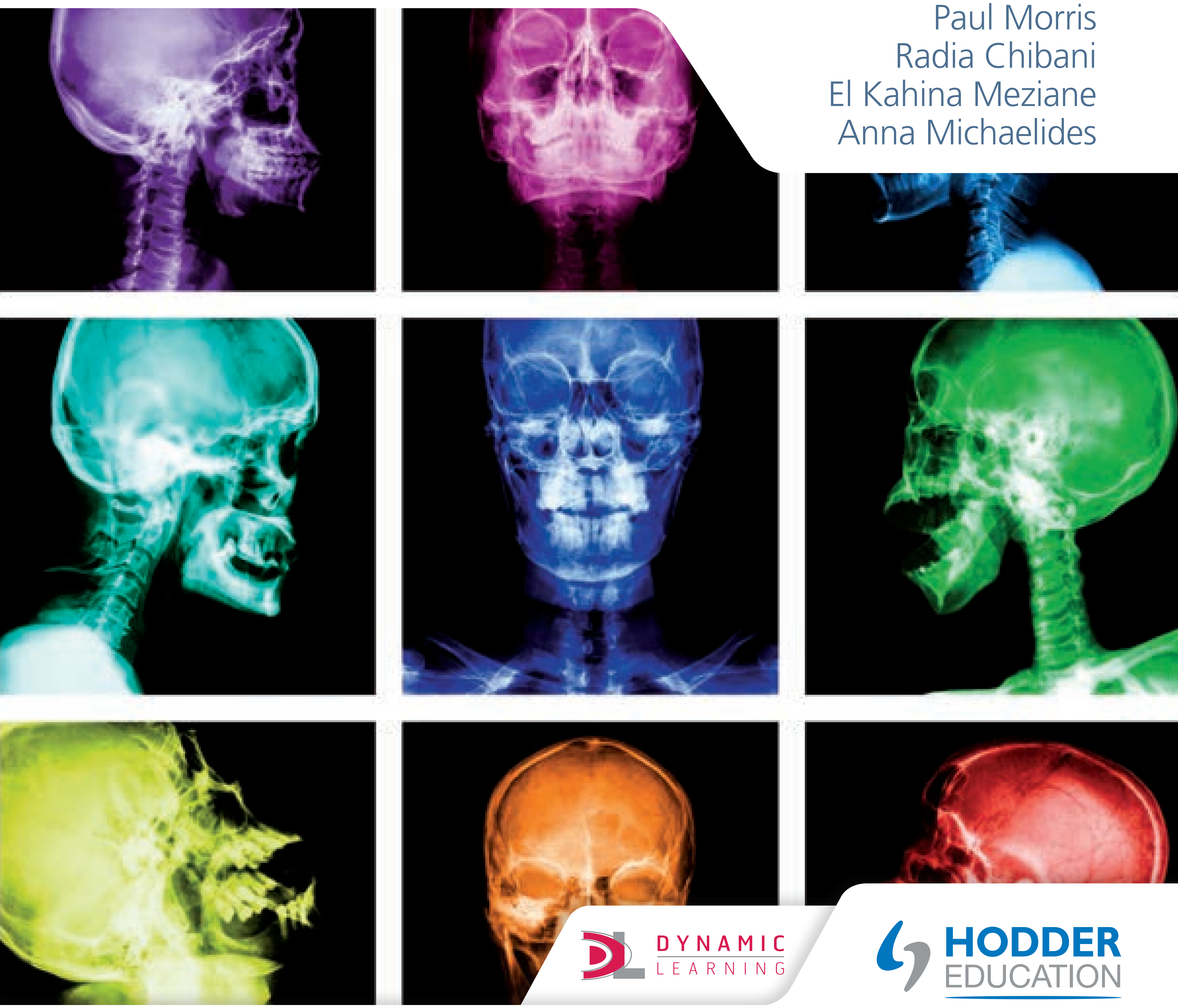

DYNAMIC LEARNING
HODDER EDUCATION

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Series editor: Paul Morris

DYNAMIC LEARNING

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Contents

How to use this book

Welcome to Hodder Education's *MYP by Concept* Series! Each chapter is designed to lead you through an inquiry into the concepts of science and how they interact in real-life global contexts.

Each chapter is framed with a *Key concept*, *Related concept* and set in a *Global context*.


Relationships Evidence Identities and relationships

1 What is science?

To be a scientist is to use experimental evidence to find relationships and test them.

CONSIDER THESE QUESTIONS:

Factual: What measurement units do scientists agree to use?

Conceptual: How do we design a valid scientific inquiry? How can we ensure that an experiment is reliable? How do scientists collaborate?

Debatable: What makes a claim 'scientific'? Has science always been around?

Now **share and compare** your thoughts and ideas with your partner or with the whole class.

(a) (b) (c)

■ **Figure 1.1** How does a horse run? (a) Prehistoric running horse cave painting, Lascaux, France; (b) *The 1821 Derby at Epsom*, Théodore Géricault (c.1821); (c) photographic images of a galloping horse, Eadweard Muybridge (c.1878)

IN THIS CHAPTER, WE WILL …

- **Find out** what scientists do and how they try to make reliable scientific knowledge.
- **Explore** the way scientists work and the stories behind today's science.
- **Take action** to work out how to distinguish unreliable claims from scientific knowledge.

2 Sciences for the IB MYP 4&5: *by Concept*

The *Statement of Inquiry* provides the framework for this inquiry, and the *Inquiry* questions then lead us through the exploration as they are developed through each chapter.

KEY WORDS

Key words are included to give you access to vocabulary for the topic. **Glossary terms** are highlighted and, where applicable, **search terms** are given to encourage independent learning and research skills.

As you explore, activities suggest ways to learn through *action*.

■ ATL

Activities are designed to develop your *Approaches to Learning* (ATL) skills.

◆ Assessment opportunities in this chapter:

Some activities are *formative* as they allow you to practise certain parts of the MYP Sciences *Assessment Objectives*. Other activities can be used by you or your teachers to assess your achievement *summatively* against all parts of an assessment objective.

Key *Approaches to Learning* skills for MYP Sciences are highlighted whenever we encounter them.

Hint

In some of the activities, we provide hints to help you work on the assignment. This also introduces you to the Hint feature in the e-assessment.


SEE–THINK–WONDER

Look at the images in Figure 1.1. What do you **see**? What does it make you **think**? What does it make you **wonder**?

KEY WORDS

collaborate
control
environment
ethical
experiment
impact
inquire
publish
risk
test

These Approaches to Learning (ATL) skills will be useful …

- Collaboration skills
- Information literacy skills
- Critical-thinking skills
- Transfer skills
- Media literacy skills

Assessment opportunities in this chapter:

The activities in this chapter will help you develop and evaluate your learning in these MYP Sciences learning objectives:

- Criterion D: Reflecting on the impacts of science

We will reflect on this learner profile attribute …

- Inquirers – we will consider how science asks questions about the world and what scientists do to find answers we can rely on.

All the images in Figure 1.1 show horses galloping. The first picture was painted in prehistoric times on the wall of a cave in Lascaux, France. The second picture is much more recent, painted in 1821 by the French artist Géricault. Did you notice that in both cases the horses appear to be running with their front and hind legs outstretched, as though they were flying through the air? Eadweard Muybridge actually photographed a galloping horse in 1878 using a basic 'stop–motion' technique. (He positioned cameras with trip-wires along a race track and ran a horse in front of a white sheet.) When the photographs were developed, the positions of the horse's legs could be seen clearly. Can you find either of the other two images in Muybridge's pictures?

Horses do not, in fact, ever adopt this 'flying' position when they gallop. So why did people persist in painting them this way? We can speculate that perhaps it was because it seemed right that horses *would* do this and that an image drawn that way would make the horse seem very fast. But the artists were certainly not painting what they *saw*. Muybridge demonstrated this by conducting an experiment which produced data that everybody could see and agree on. This illustration might guide us in our inquiry in this chapter: What is science?

1 What is science? 3

We will reflect on this learner profile attribute …

- Each chapter has an *IB learner profile* attribute as its theme, and you are encouraged to reflect on these too.

Links to:

Like any other subject, science is just one part of our bigger picture of the world. Links to other subjects are discussed.

You are prompted to consider your conceptual understanding in a variety of activities throughout each chapter.

We have incorporated Visible Thinking – ideas, framework, protocol and thinking routines – from Project Zero at the Harvard Graduate School of Education into many of our activities.

You can measure your conceptual understanding using the summary problems at the ends of the chapters, organized by level of difficulty.

Finally, at the end of the chapter you are asked to reflect back on what you have learnt with our *Reflection table*, maybe to think of new questions brought to light by your learning.

<table>
<tr><th colspan="6">Use this table to evaluate and reflect on your own learning in this chapter</th></tr>
<tr><td>Questions we asked</td><td>Answers we found</td><td colspan="4">Any further questions now?</td></tr>
<tr><td>Factual</td><td></td><td colspan="4"></td></tr>
<tr><td>Conceptual</td><td></td><td colspan="4"></td></tr>
<tr><td>Debatable</td><td></td><td colspan="4"></td></tr>
<tr><td rowspan="2">Approaches to learning you used in this chapter</td><td rowspan="2">Description – what new skills did you learn?</td><td colspan="4">How well did you master the skills?</td></tr>
<tr><td>Novice</td><td>Learner</td><td>Practitioner</td><td>Expert</td></tr>
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<tr><td>Learner profile attribute(s)</td><td colspan="5">Reflect on the importance of this learner profile attribute for your learning in this chapter.</td></tr>
<tr><td></td><td colspan="5"></td></tr>
</table>

EXTENSION

Extension activities allow you to explore a topic further.

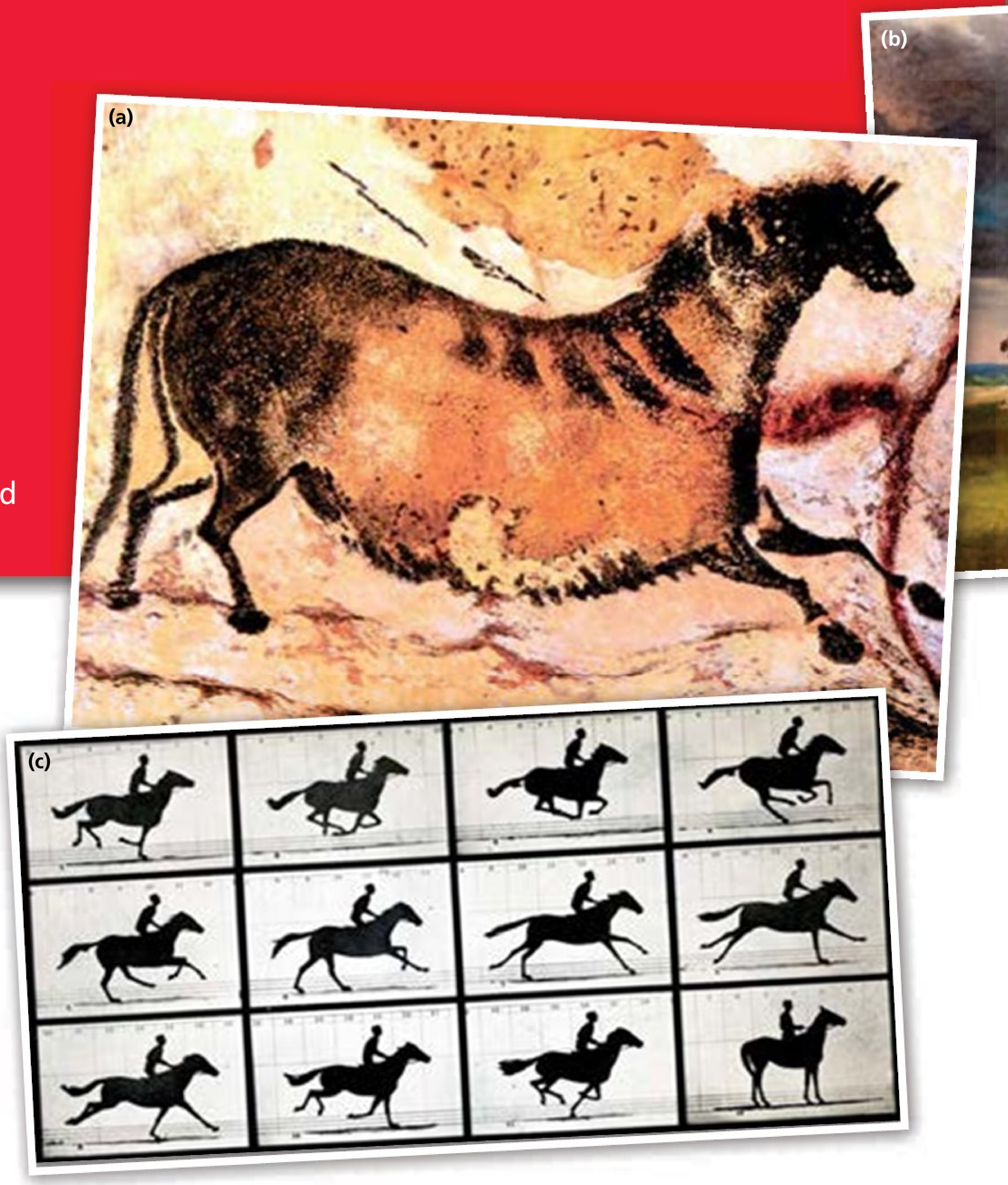
! Take action

- While the book provides opportunities for action and plenty of content to enrich the conceptual relationships, you must be an active part of this process. Guidance is given to help you with your own research, including how to carry out research, guidance on forming your own research question, as well as linking and developing your study of science to the global issues in our twenty-first-century world.

Relationships | Evidence | Identities and relationships

1 What is science?

To be a scientist is to use experimental **evidence** to find **relationships** and test them.



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- **Criterion D:** Reflecting on the impacts of science

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Figure 1.2 How well do you understand the devices you use?

The modern world is highly technological; technology is the application of scientific understanding to solve real-life problems. Yet few people understand the science behind many of the devices they use every day, from microwave ovens to smartphones to aircraft to radios.

ACTIVITY: The word is science

ATL

- Collaboration skills: Listen actively to other perspectives and ideas; Give and receive meaningful feedback

In this activity you will work collaboratively to collect ideas about what scientists do.

Either use a shared online document or small pieces of paper to **write down** the first five words that come into your mind when you ask the question:

'What do scientists do?'

Now take all of your words and enter them into a word-cloud generator such as Wordle (**www.wordle.net**) or Word it Out (**https://worditout.com/word-cloud/create**).

Generate your word cloud. What does it show you?

As a class, **discuss** the results. Are the largest words the ones you think are most important? Share your views with the class.

Display the word cloud in your classroom and refer to it as you progress through this inquiry.

ACTIVITY: Science or not?

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument

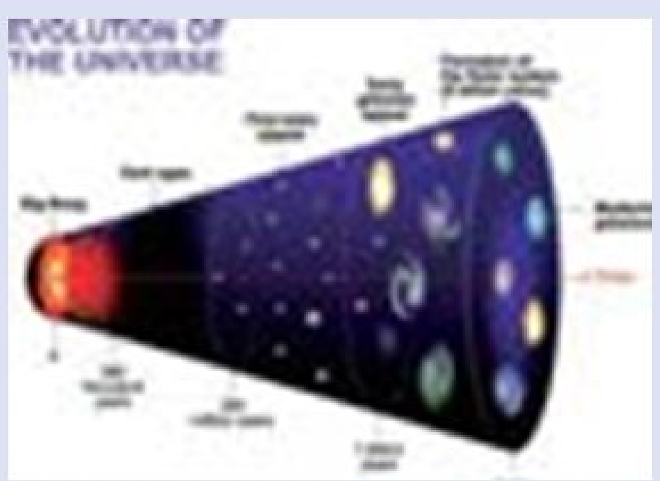
1. **Can you put the ideas in Table 1.1 in order of their 'invention' (i.e. when did people suggest them)?**
2. **Now categorize the ideas into three groups:**
   - **ideas that were *never* considered to be 'science'**
   - **ideas that *used* to be considered 'science' (but no longer are)**
   - **ideas that are currently considered to be 'science'.**
3. **Discuss how you decided on the different groups. What criteria did you use?**

	**Wave–particle duality** All matter behaves like waves of energy in space; conversely, all waves behave like particles of matter. Light, for example, can behave like a wave travelling through space, but it can also behave like tiny particles of matter called 'photons'. Even though these two properties can lead to completely contradictory results in the same experiment, this is just because our experiments are not adequate to represent what light really is: both waves and particles.
	**Lamarckian evolution** Living creatures adapt to their environment. Thus, a repeated need means that creatures develop a certain ability, which is developed over each generation. The giraffe has a long neck because over many generations giraffes have stretched to reach the highest leaves in a tree. The grandchild of blacksmiths is likely to be born with strong arms and will pass this propensity to his or her children.

Table 1.1

What makes a claim 'scientific'? Has science always been around?

To many people, science tells us the 'real' truth. To others, it is just another point of view. Where does your opinion lie? Perhaps one of the most important things to realize about science is that it is (as the philosopher Karl Popper put it) 'open' knowledge. Scientists should not be afraid of being proved wrong. In some ways, that is the whole point of science: to learn from our mistakes, in order to know with greater certainty next time.



Big Bang theory

The Universe – not only space, but time itself – began in a single point around 15 billion years ago. This point was called the 'singularity'. After this all of space–time 'unfolded' and cooled, so that energy was turned into matter with different properties. The rate of unfolding of space–time depends on the strength of forces in the Universe, most important of all gravitation.

Alchemy

All natural substances have properties related to their place in the Universe. They consist of a mixture of the four principal elements – Earth, Air, Fire, Water – in different quantities. Thus, heavy elements such as lead contain more Earth than Air. Each element is also responsible for a part of the human body, and imbalances in the correct amounts of elements lead to illness.

The 'perfect element' is the fifth element, or *quintessence*, also known as the 'Philosopher's Stone'. This element can convert all elements into any other element.

Phrenology

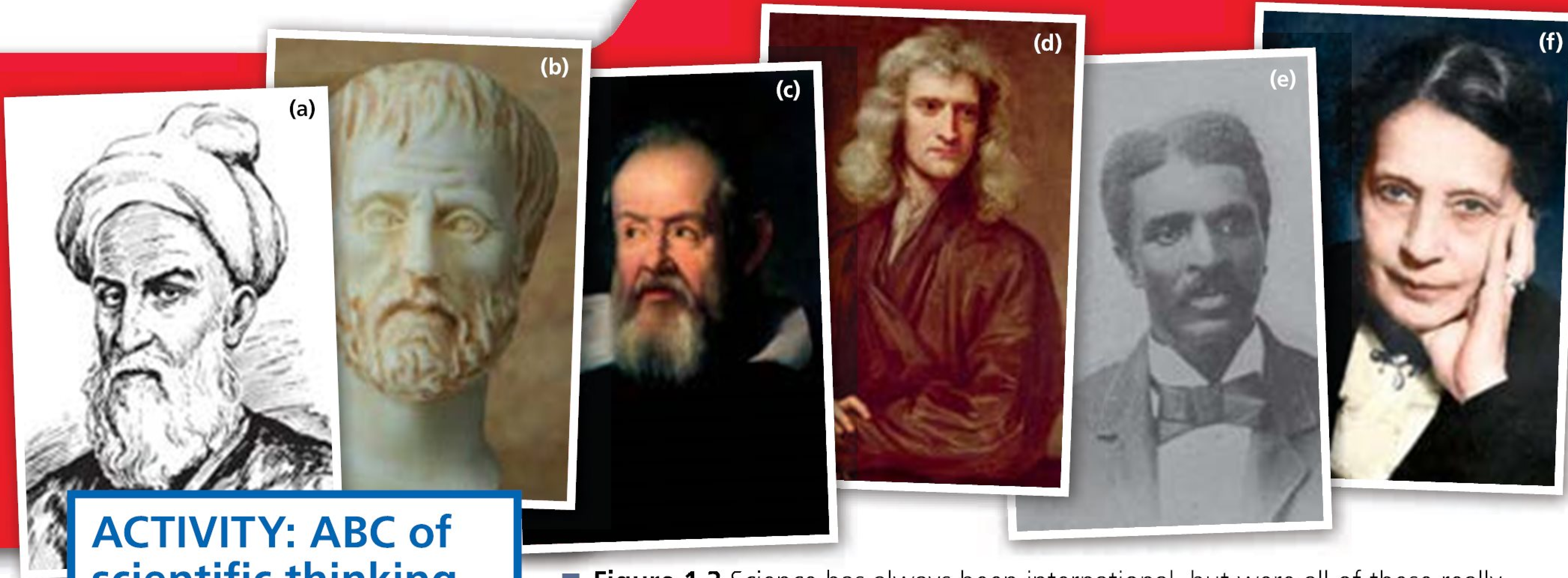
Each part of our brain is responsible for a different aspect of our personality. The distinguishing features of our personalities are caused by different growth rates in different parts of our brains. We can therefore 'read' our personalities by looking for bumps on the cranium that indicate which parts of the brain have developed the most.

Astrology

All events on Earth are determined to some extent by the motions and positions of the five planets: Mercury, Venus, Mars, Jupiter and Saturn. Our own lives are strongly determined by the positions of these planets at the time of our birth, and subsequent events can be related to planetary motions.

Plate tectonics

The Earth's surface is in fact a very thin layer of hard rock that floats on a softer substrate of molten lava. The surface is cracked into 'plates' which have moved over many billions of years. For this reason, the continents as we see them today were different many millennia ago: originally, all land on Earth was one huge continent which has been called 'Gondwanaland'.



■ **Figure 1.3** Science has always been international, but were all of these really 'scientists'? Were they always right? (a) Ibn Sīnā, known as Avicenna (980–1037 CE); (b) Aristotle (384–22 BCE); (c) Galileo (1564–1642 CE); (d) Newton (1642–1727); (e) George Washington Carver (c.1860–1943); (f) Lise Meitner (1878–1968)

ACTIVITY: ABC of scientific thinking

ATL

- Information literacy skills: Access information to be informed and inform others

Look at the scientists in Figure 1.3.

Research the work of an important scientist or mathematician who is from a culture different to your own.

Summarize one of the important contributions they made to our understanding of the world. **Outline** what problem of the time this contribution solved or what it enabled us to do.

Describe some of the challenges your scientist faced, whether scientific, political, economic, social or otherwise.

Don't forget to **document** all your sources using a recognized citation standard and bibliography.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion D: Reflecting on the impacts of science.

To Greek classical thinkers, the world of the senses – that which we observe – was unreliable and uncertain, because the senses could be deceived. For many of them (with notable exceptions, such as Aristotle) *true* knowledge could only be obtained through *thinking*. This view of knowledge is sometimes called **rationalism**.

In Europe it took a long time to change this view and a large number of writers and thinkers contributed to the process, such as Thomas Aquinas, Francis Bacon and Galileo Galilei. By around 1600, however, European thinkers were beginning to reconsider the role of observation in making knowledge. Francis Bacon, for example, asked: why should thinking be any more reliable or certain than what we, ourselves, can experience? He proposed that we could be more certain about the world if we made careful, controlled observations of the way things behaved in it.

The idea that knowledge can be gained from observation and experience is sometimes called **empiricism**.

However, if our knowledge of the world is to be reliable, not just any experience or observation will do. Our observations must be controlled carefully so that we can determine the exact **relationships** between things; in other words, we must do an *experiment*.

Links to: Language and literature

The language of science

ATL

- Transfer skills: Inquire in different contexts to gain a different perspective

The word 'experiment' derives from the Latin *experiri*, meaning *experience*. If you study a Latinate language such as Italian, French or Spanish, you may know that the word for experiment is the same as the word for experience.

Use Google 'ngrams' to find out when the word experiment began to be used more frequently in books and other texts: **https://books.google.com/ngrams/**

How do we design a valid scientific inquiry? How can we ensure that an experiment is reliable?

Galileo Galilei (Figure 1.3c) was one of the first people to realize that reliable experiments required controlled variables. A variable is any factor that can be controlled or measured in order to investigate a **relationship** experimentally.

Imagine an experimental inquiry to be like a sort of machine. The **controls** of the machine determine the **outcomes** that we can measure (Figure 1.4). We feed in our questions and out of the process – hopefully – come the answers!

While scientific inquiry may begin with wonder, scientific questions need to be a little more focused than that. As scientists, we have to make questions that can be tested in some way, such that we can find an answer or explanation for what we observed. Often a problem in nature will turn out to be much more complicated than it seems at first and we will only be able to answer a big question by first identifying a number of smaller questions and finding the answers to those.

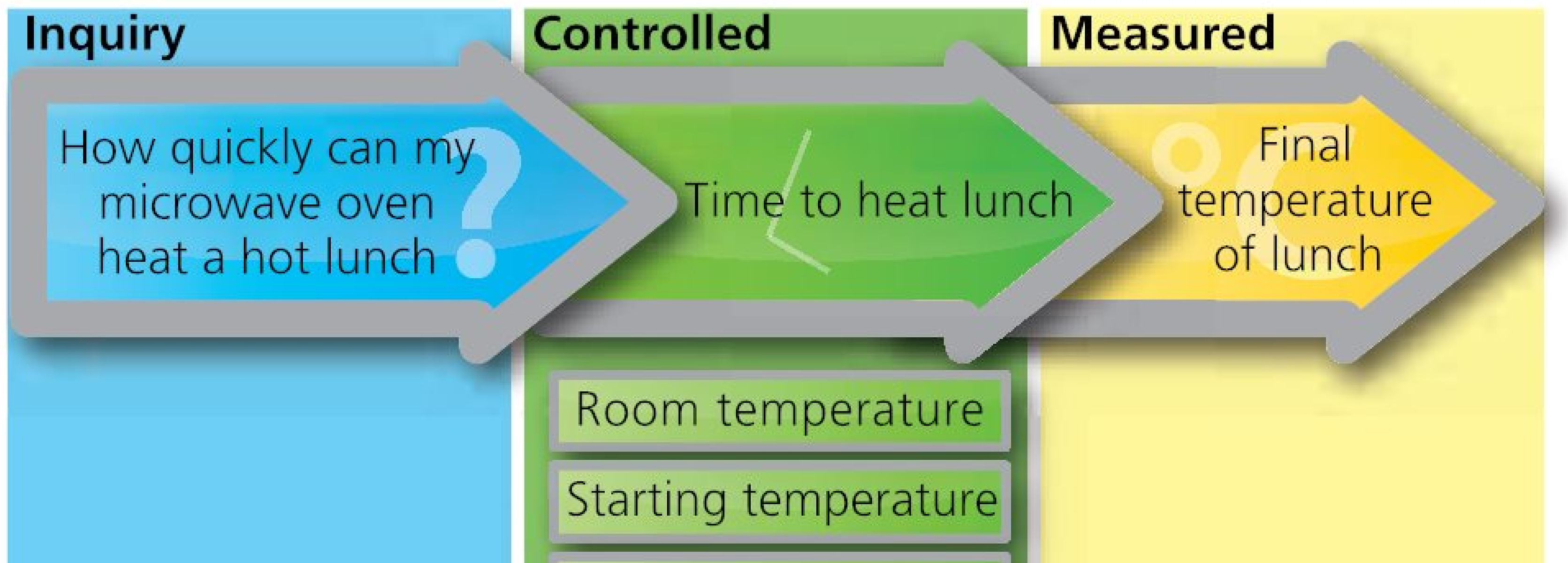


Figure 1.4

Look again at Figure 1.4. What other variables might affect the temperature of my lunch? If we change any of these, they might also affect the outcome – the final temperature of my lunch.

We therefore have to divide the **controlled variables** into those we will **change** and those we will **keep the same**. The variable that we will be changing in the experiment is called the independent variable (because it depends only on us); the variable that is being measured is called the dependent variable.

ACTIVITY: The right variable for the job

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument

For the different experimental inquiries below, choose variables that it might be important:

- **to control by changing**
- **to control by keeping the same**
- **to measure.**

Variables

temperature	colour	area
time	brightness	speed
height	distance	

Experimental inquiries

- **How long does an ice cube stay frozen?**
- **What size of parachute will save a dropped egg?**
- **What is the best colour to wear if you want to keep cool?**
- **How long does an aircraft stay on the runway before it can take off?**

Asking the right question

In designing an experiment, the first thing we do is select our variables and figure out which variables we are going to change (independent variables) and which we are going to measure (dependent variables).

To do this, we need to have an idea of the problem we are trying to solve. This is why the first stage in the scientific investigation cycle is to write an 'inquiry question' for the experiment. A good inquiry question should include the variables that you are going to control, for example:

How does variable 1 affect variable 2?

or

What is the relationship between variable 1 and variable 2?

Once we have the question and the variables, we can suggest what we think the answer might be. When scientists suggest a **theory** as an explanation for the way something might work, it is called a **hypothesis**. If we then state exactly what we expect to see happening in a given situation, it is called a prediction. For example, I might make a *hypothesis* that whenever the temperature drops in winter, it is more likely to snow; this might lead me to *predict* that on Saturday it will be snowing.

Some scientific inquiry is carried out by looking at data that others have already gathered; these are called **secondary data**. Much science, however, requires new or **primary data**. Scientists need to carry out their experiments to gather data in a controlled environment: the laboratory. A laboratory is a specially equipped room where all the equipment and apparatus the scientists require is available. It is kept very clean and tidy to ensure that nothing can affect the experiments carried out, other than the effect of the independent variable.

In *MYP Sciences by Concept 1*, we explored the laboratory as a working environment. All the experiments you will carry out in this book require care and safe practice, so this is a good time to review the laboratory codes again.

We follow safety rules in order to minimize risk. Before you begin an experiment it is a good idea to carry out a **risk assessment**. This involves reviewing in advance everything you will do in the experiment and considering what possible dangers this could present. You should then re-evaluate your experiment design to reduce such risk. Search for **risk assessment template science lesson** or use the example shown in Table 1.3.

ACTIVITY: Making up the rules

ATL

- Collaboration skills: Take responsibility for one's own actions

Every laboratory needs a 'code' to make sure that all experiments are carried out safely and scientifically.

In pairs, **discuss** and **complete** a copy of Table 1.2 by **explaining** why it is important to take the safety measures given in the first column.

As a class, brainstorm any other safety measures that you think might be important in the laboratory.

When you have finished:

- **design and make a poster illustrating any of the safety measures so that other MYP students will understand**
- **design and make a 'safety checklist' to use before you begin any experiment.**

Safety measure	Reason
keep bags, coats and books in a safe place out of the way	
wear protective clothing and safety glasses when instructed	
walk, don't run	
do not put anything in your mouth	
do not listen to music while working	
wash hands carefully after using chemicals or organic substances	
tie back long hair	

Table 1.2 Laboratory rules

Date assessment completed: ______________________

A = Probability: 1 = Not likely B = Severity : 1 = Mild

2 = Possible 2 = Medium

3 = Likely 3 = Severe

Hazard	A	B	C (A × B)	Action to reduce risk

■ **Table 1.3** Risk assessment

It is also important to consider the effect of our actions on the environment, both inside the laboratory and outside. We should consider the way we dispose of waste materials, especially if we are using chemicals or other 'special' materials. Remember that in a laboratory, everything we use is scientific apparatus, even if it is something we might consider quite usual at home. This is why we never put anything in our mouths during experiments, we always clean any apparatus and surfaces, and we always wash our hands after we have finished.

Will your experiment involve living things or possibly affect others? If so, you should also consider whether or not your actions will be **ethical**. Is anything you plan to do likely to cause harm or upset to other living things? This can be difficult for scientists to judge and they must work closely within ethical guidelines such as those provided by the International Baccalaureate Organization (IBO) for students.

Find out about the ethical guidelines for the IB MYP and DP. Ask your teacher to find these documents and **discuss** them in class:

- IB animal experimentation policy
- Ethical guidelines for extended essay research and fieldwork
- Ethical guidelines for IB DP Psychology.

A useful preparation is to write an **environmental and ethical impact assessment** of your experiment, where you consider the effect of your experiment on the living and non-living environment.

ACTIVITY: Thinking about environmental impact

ATL

- Collaboration skills: Take responsibility for one's own actions

In pairs, brainstorm as many ways as possible that a scientific experiment might affect the environment, both in the laboratory and outside it. Consider how your experiment might also affect the wellbeing of other living things.

Share your ideas with the class and collect all the class ideas together.

Discuss what action you should take to minimize the impact of the factors you have identified.

Organize the impact factors and the actions in the form of an easy-to-use checklist similar to the one you wrote for the activity *Making up the rules*.

What measurement units do scientists agree to use?

■ **Figure 1.5** A cabinet of international weights and measures. Before standardization, different places all used different measurements, making it very difficult to trade fairly! (The cabinet can be found in the Winton Gallery at the Science Museum, UK)

In Chapter 1 of *MYP Sciences by Concept 2*, you may have explored how humanity has created different ways to make measurements of the natural world. The first recorded forms of measurement were probably based on the size of parts of the human body. Today, the two most common forms of measurement in use are the **metric system** and the **imperial system**. Scientists worldwide use the metric system of measurement.

During the seventeenth and eighteenth centuries in Europe, philosophers were influenced by the rediscovery of classical thought from Greece and Rome. The revolution in France from 1789 not only sought to change the way society was organized or who was in charge, but also to reorganize the way humanity thought about time and space. The revolutionaries introduced a new calendar based on 10 months a year, rather than the 12 inherited from ancient times, and in 1799 the revolutionary government created new standards of measurement for length and mass, called the metre and the kilogram. These in turn were divided logically in units of 10, 100 or 1000 as the 'metric' system. The measurements were standardized using a platinum rod and a mass which were kept in the *Archives de la République* in Paris.

Just as the political changes in France were not popular everywhere in Europe, the new 'rational' measures were not immediately taken up elsewhere. In France itself the 'new calendar' of 10 months was abandoned when Napoleon Bonaparte came to power. However in the nineteenth century, physicists developed a system of units that aimed to derive all measurements from a small number of basic metric units. This was the basis of the metric Système International d'Unités (or SI unit system), although it wasn't given this name until 1960.

Unit of length	meter/metre	length of the path travelled by light in vacuum during a time interval of $\frac{1}{299\,792\,458}$ of a second
Unit of mass	kilogram	the mass of the international prototype of the kilogram
Unit of time	second	duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom

■ **Table 1.4** Definitions of the SI base 'mechanical' units (note that there are seven base units in total)

THINK–PAIR–SHARE

What do you notice about the definitions of the units in Table 1.4?

What has changed since the first definitions of the metre and kilogram in France in 1799?

Why do you think the definitions have been changed?

Power of 10	Prefix
$\times 10^{-15}$	femi
$\times 10^{-12}$	pico
$\times 10^{-9}$	nano
$\times 10^{-6}$	micro
$\times 10^{-3}$	milli
$\times 10^{-1}$	deci
$\times 10^{3}$	kilo
$\times 10^{6}$	mega
$\times 10^{9}$	giga
$\times 10^{12}$	tera

Table 1.5 Common prefixes

Accuracy and precision

When scientists make measurements, they need to be sure that the measurements are reliable. This means that whoever makes the measurement, wherever it is made and under whatever conditions, the answer obtained will always be the same.

If a number of measurements are precise, they will be in close agreement with each other.

If a measurement is accurate, it will be close to an expected value.

A *Sciences Inquiry Cycle* (see Figure 1.6) can be used to guide us whenever we design our own investigations for our inquiry questions in this book.

Since scientists have to use large and small numbers so often, it could be quite tedious to have to write out the dimensions of objects in metres all the time, along with the powers of 10. For this reason, the SI system includes a series of prefixes for different scales. A new prefix is used every time a multiple of 1000 or 10^3 occurs. You may have encountered some of these already in relation to computer systems.

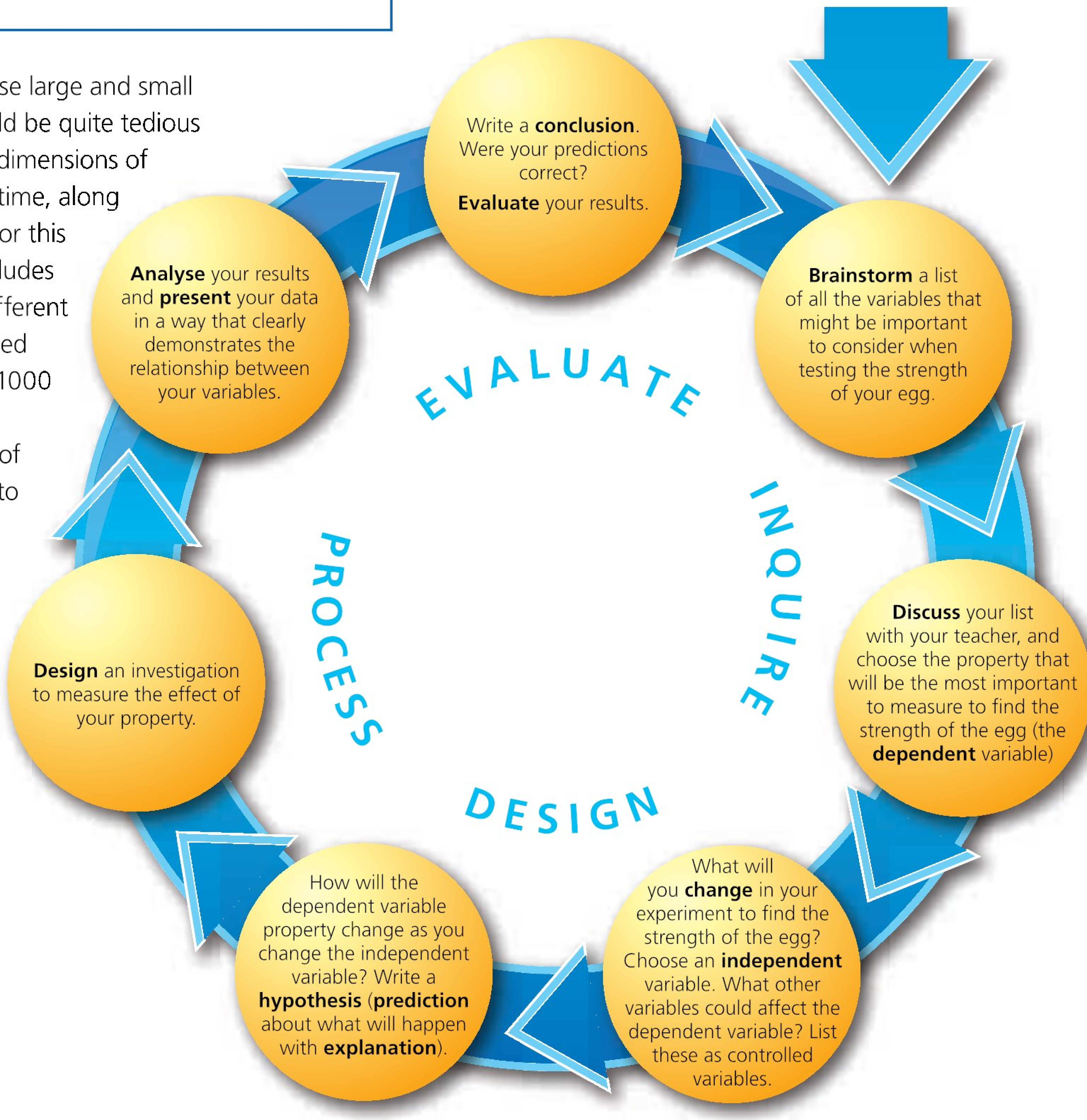


Figure 1.6 A *Sciences Inquiry Cycle* for investigating the strength of eggs!

How do scientists collaborate?

Sometimes in history, a person comes along who can do everything themselves (see *Meet a scientist: Leonardo da Vinci*). However, in most cases, science is a collaboration between a number of scientists; sometimes across the world, sometimes between the different disciplines within science, such as physics, chemistry and biology, sometimes with technological disciplines such as computer science.

Scientists must make sure that their new knowledge is as reliable as possible. When a new discovery is made, scientists must publish their work in a recognized scientific journal and may present it at a conference. To be included in a journal, the work undergoes **peer review**. This means that the work is checked by other experts in the field and the experiment may also be **repeated** by other scientists to verify that the results are the same as those claimed. In doing so, scientists are checking to ensure that they all work to the highest standards of academic integrity – just as you must in your MYP studies.

Science is really one big debate that continues to throw up new questions about the world.

DISCUSS

Find out about one of the following scientific projects:

- **The Large Hadron Collider**
- **The Human Genome Project**
- **The ITER Fusion Reactor**
- **Intergovernmental Panel on Climate Change (IPCC)**

Who is involved in each project? What kind of experimental work do they do? **Suggest** why the projects require collaboration.

EXTENSION

Look at the table of scientific journals at the following link: **www.scimagojr.com/journalrank.php?category=2701**

In order to 'rank' these journals, what do you think is being measured?

MEET A SCIENTIST: LEONARDO DA VINCI

Leonardo da Vinci was an Italian **polymath** who was born in April 1452. He was hugely influential as an artist, with his famous paintings such as the *Mona Lisa*. Da Vinci's talents and knowledge went far beyond art, however. He was expert in science, mathematics, engineering, music, architecture, archaeology, literature, geology, anatomy, botany, physiology – the list goes on! His famous drawing *The Vitruvian Man,* in which he studied the proportions of the human body, is a marriage between art and science. He was fascinated by the human body and was allowed to dissect corpses in hospitals in Italy. He also dissected animals and compared them to human bodies. This is why his anatomical drawings of the human musculoskeletal system and embryos are so detailed and accurate.

■ **Figure 1.7** A portrait of Leonardo da Vinci (1452–1519)

Leonardo was a talented engineer too. His engineering skills could be seen in his sketches and designs of flying machines (Figure 1.8). He laid the foundation for biomechanics with his studies on the mechanical processes involved in human and animal movement. In modern times, his designs have been used to build working models. Examples of his designs include a parachute, a machine for testing tensile strength, an adding machine, hydraulic pumps, a flapping ornithopter and a machine with a helical rotor (a helicopter).

■ **Figure 1.8** Exhibition of da Vinci flying machines in Venice, Italy

Leonardo da Vinci relied on detailed observations of natural phenomena to drive his own experiments based on patterns he identified. His scientific thinking process had a great influence on his art. In his most famous painting, *The Last Supper* (Figure 1.9), he applied his theories on the physics of light, shade and angles and the rules of optics.

■ **Figure 1.9** Leonardo da Vinci's painting, *The Last Supper.* Da Vinci applied his theories on the rules of optics and visual perception to draw the diners around the central figure of Jesus in the painting.

Take action: Exposing fake news

ATL

- Media literacy skills: Demonstrate awareness of media interpretation of events and ideas

- We have seen in this chapter how science stories are very popular in the media. Sometimes, though, the media get it wrong and people can be misled, because not everybody thinks scientifically.
- Here are a few of the most common misconceptions, which you may have investigated in Chapter 1 of *MYP Sciences by Concept 1*.

Figure 1.10

- Research these or search other popular scientific misconceptions. Make a poster, web presentation or a movie in which you 'debunk' these misconceptions by explaining the real science behind them!

Reflection

In this chapter we have **outlined** the way that scientists work to make new knowledge. We have **categorized** ideas according to whether or not they are 'scientific' and so **suggested** some criteria for scientific ideas. We have **designed** laboratory codes for safety and for environmental risk. We have **identified** the measurement units that scientists use. We have **discussed** how scientists collaborate across the world and between scientific disciplines.

Use this table to reflect on your own learning in this chapter					
Questions we asked	Answers we found	Any further questions now?			
Factual					
Conceptual					
Debatable					
Approaches to learning you used in this chapter	Description – what new skills did you learn?	How well did you master the skills?			
		Novice	Learner	Practitioner	Expert
Learner profile attribute(s)	Reflect on the importance of being an inquirer for your learning in this chapter				
Inquirer					

2 How does scale matter?

Changing the **scale of things** allows us to **make connections** and **build models** that help us understand how the world is structured.

Figure 2.1 The idea of changing size has been a popular subject for science fiction

CONSIDER THESE QUESTIONS:

Factual: How are living organisms structured? What building blocks do scientists use to describe living and non-living matter? What holds matter together?

Conceptual: How does changing scale change our understanding of nature?

Debatable: To what extent does our everyday experience limit our understanding of the very small and the very large?

Now **share and compare** your thoughts and ideas with your partner or with the whole class.

These Approaches to Learning (ATL) skills will be useful …

- Information literacy skills
- Critical-thinking skills
- Creative-thinking skills
- Transfer skills
- Communication skills
- Reflection skills
- Collaboration skills

We will reflect on this learner profile attribute …

- Open-minded – we will consider how changing point of view and perspective might change our understanding of the world.

Assessment opportunities in this chapter:

The activities in this chapter will help you develop and evaluate your learning in these MYP Sciences learning objectives:

- **Criterion A:** Knowing and understanding
- **Criterion C:** Processing and evaluating
- **Criterion D:** Reflecting on the impacts of science

KEY WORDS

atom	nucleus
cell	organ
ecology	particle
ecosystem	

IN THIS CHAPTER, WE WILL …

- **Find out** about the 'building blocks' of organic and inorganic matter.
- **Explore** the way in which changing the scale at which we observe and measure the natural world changes our understanding of it.
- **Take action** to raise awareness of how different perspectives in science can both extend and sometimes limit our knowledge and understanding.

SEE–THINK–WONDER

Look at the images in Figure 2.2. What is changing? What do you **see**? What does this make you **think**? What does it make you **wonder**?

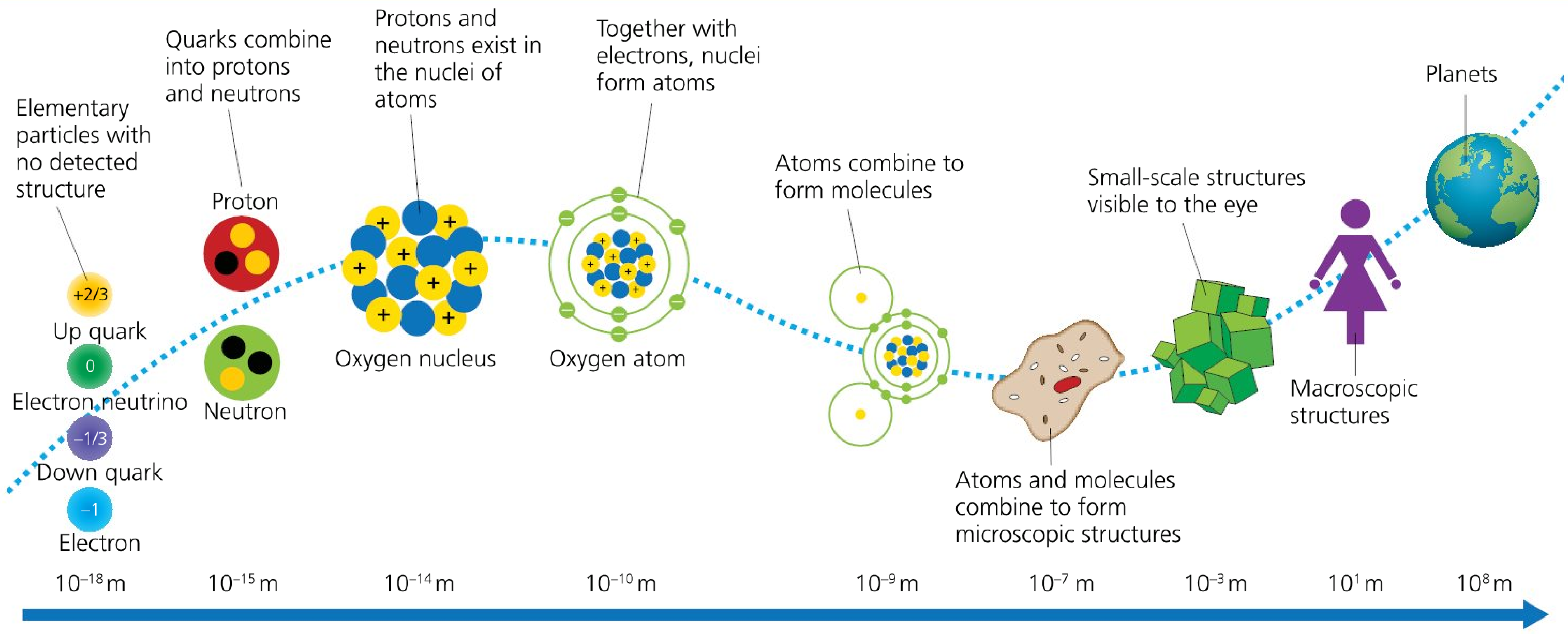


Figure 2.2 The scale of things

ACTIVITY: Principal, I shrunk the science class!

ATL

- Creative-thinking skills: Consider multiple alternatives, including those that might be unlikely or impossible; Create original works and ideas; Use existing works and ideas in new ways
- Communication skills: Use appropriate forms of writing for different purposes and audiences
- Information literacy skills: Access information to be informed and inform others

We must be careful not to confuse science fiction with science fact. The idea of shrinking matter to a different scale is not realistic, as we will see in this chapter. In reality, scientists have to make do with using instruments and measurements to deduce how the Universe works at different scales. Still, imagination also plays an important part in science as we saw in Chapter 1; asking 'what if …?' questions can lead to new hypotheses and so to new science.

Imagine that you are working with a research scientist who has somehow found a way to change size. Choose three different scales and draft a newspaper report describing what you see at those different scales. Use diagrams and pictures to illustrate your discoveries!

There are many online simulations that allow you to explore the Universe at different scales. **Explore** online using one of these website to find out what the Universe looks like at different scales:

http://apod.nasa.gov/apod/ap120312.html (requires Adobe Flash)

http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/ (requires Java).

At the end of this chapter, we will return to your draft report to see how it might be improved.

Figure 2.2 shows how changing our perspective can change the information that we have about the world. Science deals with the whole Universe, from the very large to the very small indeed. In this chapter we will explore how changing the scale of our observations gives us a different perspective and we will think about the connections between the systems and processes we observe at different scales. Along the way, we will encounter and use the tools of the different science disciplines of physics, chemistry and biology and see how they each work across different scales of observation.

How does changing scale change our understanding of nature?

WHAT IS SCALE?

Links to: Mathematics

ATL

- Transfer skills: Make connections between subject groups and disciplines

Important key concepts in MYP Mathematics are form and relationships.

Form in mathematics concerns the way that appearances can tell us about the purpose or the function – what something does. *Relationships* in mathematics concerns the way that things connect. So it should not surprise us that mathematics will help us work with relationships between things at different scales! When scientists are dealing with very large scales or very small scales, they must calculate very large and very small numbers. Our usual unit of length – the metre – is made to be useful to us, in our 'scale' for the Universe.

In standard notation:

10^1 is said 'ten to the power of one'	$= 10$
10^2 is said 'ten to the power of two'	$= 10 \times 10 = 100$
10^3 is said 'ten to the power of three'	$= 10 \times 10 \times 10 = 1000$

and so on …

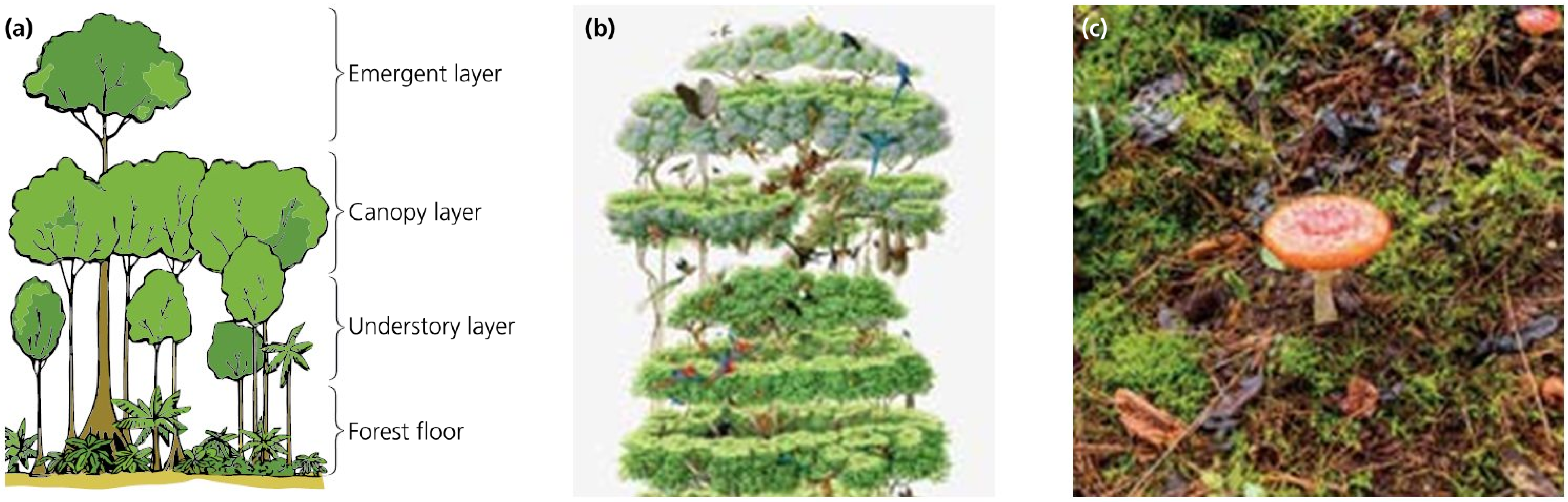
Notice that although $10^0 = 1$, for values in the range 1 to 10 we would just give the number itself. So '5' would simply be written as '5', not as 5×10^0.

For numbers that are smaller than 1 we have to go the other way, making the power of 10 smaller and smaller. We use negative powers of 10 to do this:

10^{-1} is said 'ten to the power of minus one'	$= 1 \div 10 = \frac{1}{10} = 0.1$
10^{-2} is said 'ten to the power of minus two'	$= 1 \div (10 \times 10) = \frac{1}{100} = 0.01$
10^{-3} is said 'ten to the power of minus three'	$= 1 \div (10 \times 10 \times 10) = \frac{1}{1000} = 0.001$

Links to: Language and literature

How many works of fiction – whether short stories, novels or movies – can you find that use the idea of changing size as inspiration? Try searching **Fantastic Voyage 1966** or **Honey I Shrunk the Kids** for some starter ideas!



■ **Figure 2.3** (a) Rainforest layers, (b) canopy layer, (c) forest floor layer

We look at things with our eyes, have a certain perception of them and form a mental image, but most of the time what we see is not what the things actually are. If we get closer or further from them we see them very differently. We walk in our cities every day and see the houses, trees, parks, lakes ... but when we fly in an aeroplane and look down at a familiar place we see a whole different picture. Our understanding of nature depends on observations and these observations depend on the scale we use to look at objects. The scale is determined by the **resolution** of the image and the **magnification** of what we look at.

In ecology, for example, changing the scale has a key role in understanding ecosystems and interactions between organisms. In a tropical rainforest, which is characterized by its layers (Figure 2.3a), our understanding of its ecosystems changes according to the scale we use. If we are within the forest and look at a specific layer, for example the predominant canopy layer (Figure 2.3b), we will see the large trees and a hugely diverse number of **fauna and flora**. However, at this scale we will not appreciate the complexity of other ecosystems and may miss many dynamic biological processes that cannot be seen until one undertakes deeper investigation. Looking at the forest floor layer (Figure 2.3c) will give a whole different experience of the rainforest. This layer only receives a very small amount of sunlight and therefore the fauna and flora found there are different from those found in other layers, as they must be adapted to live in such conditions.

There are many other examples where we experience such changes of understanding of nature depending on the scale we use to look at it.

The discovery of different microscopes has revolutionized our understanding of many biological processes or organisms.

Scientific discoveries depend on the available tools and technologies.

Light microscopes revolutionized science in enabling us to see cells, for example, and many other things as small as 500 nanometres (5×10^{-7} m). The later invention of **electron microscopes** offered us a whole new level of understanding. Cells can now be seen at a higher magnification, showing different organelles and enabling us to understand the metabolic reactions that happen inside them. The discovery of the **fluorescent microscope** has also helped scientists understand many processes by tagging different markers in cells with fluorescent labels and allowing us to see their location and follow their pathways through those cells.

EXTENSION

Explore this website and meet a scientist who is passionate about microscopy:
www.sciencelearn.org.nz/resources/497-the-microscopic-scale

Watch this video about 'the wacky history of the cell theory' which looks at how natural scientists collaborated with physicists to use microscopes and make revolutionary discoveries:
www.youtube.com/watch?v=4OpBylwH9DU

THE MICROSCOPIC SCALE

ACTIVITY: Zoom in!

ATL

- Information literacy skills: Make connections between various sources of information

Look at the second column of Table 2.1 showing an image of some bedbugs as you can see them on a bedsheet; they look like small black specks. If you get closer and look at one under a light microscope, you will see it looking like the image in the third column, which has more visible features. If you zoom in further under a scanning electron microscope (SEM, last column), you will see even more details on the surface, making the little insect look like a beast!

Copy and complete the examples in the table by finding how other things look to the naked eye, then get closer and search how they look under a light microscope and an electron microscope.

You may extend your research to other objects/organisms that are not listed in the table.

Hint

A scanning electron microscope (SEM) will give you the details of the surface structure and a transmission electron microscope (TEM) will give you the details of the inside structure of things. In your search, make sure you enter the name of the organism and the type of microscope in a search engine; for example: tardigrade under scanning electron microscope.

EXTENSION

Explore the history of the electron microscope:
http://authors.library.caltech.edu/5456/1/hrst.mit.edu/hrs/materials/public/ElectronMicroscope/EM_HistOverview.htm

Links to: Design

Every scientific discovery was made using tools and instruments. Designing scientific instruments and apparatus requires careful consideration, so they are fit for purpose. Function is much more important than how these tools look. Designers of laboratory equipment develop and create tools that solve problems and advance scientific discovery. Find out more about these companies by searching: **laboratory equipment, design and scientific equipment**.

SEE–THINK–WONDER

Look at Figure 2.4, and consider the questions below. What do you **see**? What does it make you **think**? What does it make you **wonder**?

How does the DNA that measures up to 2 m when stretched fit inside a nucleus of 10 micrometres, inside a cell of 20–30 micrometres diameter?

Figure 2.4 DNA inside the cell

Object/organism	As seen by the naked eye	As seen under a light microscope	As seen under an electron microscope
bedbug			
what's on your skin (skin bacteria): **staphylococcus epidermidis under light microscope** and **under electron microscope**			
coffee beans: **coffee beans under light microscope** and **under electron microscope**			

Table 2.1

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

ACTIVITY: How does it fit inside?

ATL

- Information literacy skills: Collect and analyse data to identify solutions

Large natural structures can fit inside smaller ones because of special adaptations: DNA **supercoils** and folds around itself and around other proteins to make **chromatin** which then folds again to make chromosomes to fit inside the nucleus. The intestine increases its surface by having villi and the intestine itself folds tightly and is held together with **mesenteric tissue** to fit inside the abdomen.

Explore the scale of things by searching **scale and magnification** and using the following link: **http://learn.genetics.utah.edu/content/cells/scale/**

Move the slider in order to zoom in and see the things that fit inside each structure until you reach the smallest structure. Notice the scale box in the top left-hand corner; see how it changes as things get smaller. Record the structures and their sizes and **organize** from large to small.

Move the slider and zoom to the level of a red blood cell. Its actual size is 8 micrometres. In the top left-hand corner notice the scale shown as a square of 10 micrometre size. You could have figured out the real diameter of the red blood cell by measuring it using a ruler and plotting this measurement on the little squares within the 10 micrometre highlighted square. You will find that the red blood cell takes up eight small squares, meaning it is 8 micrometres.

Now **calculate** the size of the following structures:

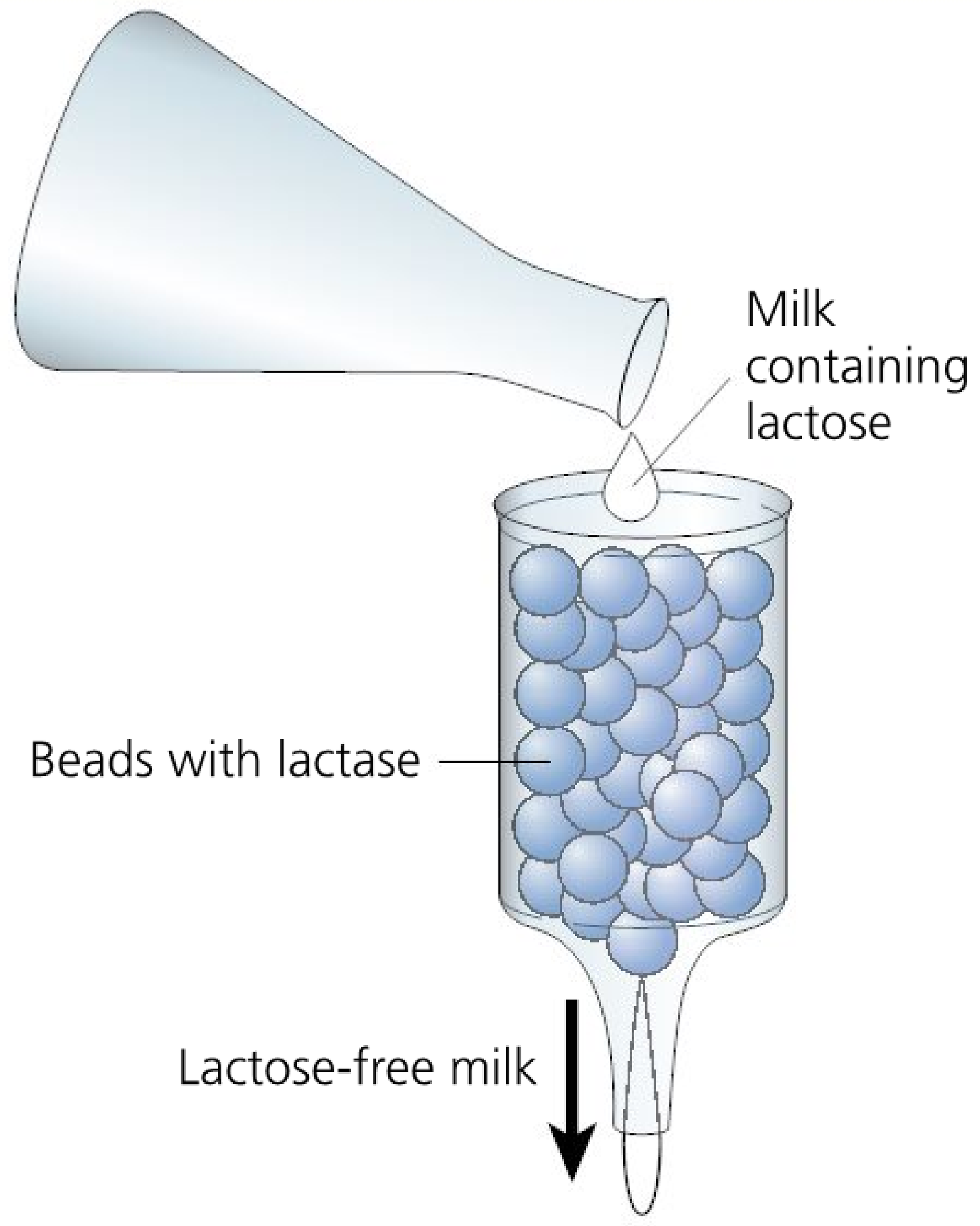
- **the length of the text 'Times regular, 12 point'**
- **the diameter of the blue nucleus inside the pink skin cell**
- **the length of the sperm cell (tail only).**

Assessment opportunities

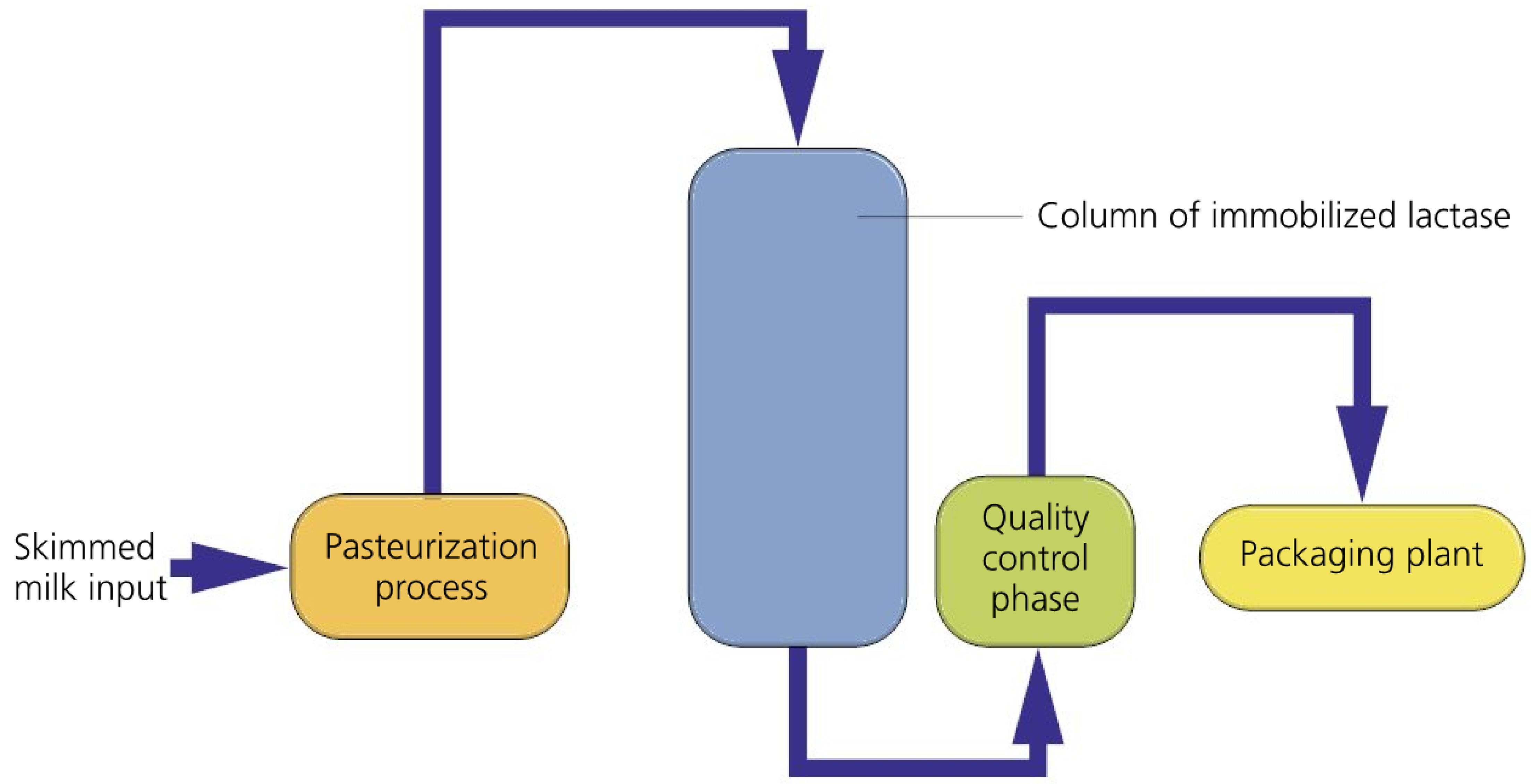
- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

SCALING IN BIOLOGICAL APPLICATIONS

Scale is not only a question of measurement and magnification. Scaling can also refer to the increase of quantities while maintaining the proportions. Scaling production can mean that we either increase the production of valuable products at a larger scale (scaling up) or we minimize the amount of substances needed to conduct tests (scaling down). Scaling up and down is key for many biological applications and processes such as the large-scale commercial production of laboratory-scale products. However, any commercial production must be tested on a small scale first before going to a large-scale production for commercial use. Small-scale productions may start in test tubes but then are scaled up in **bioreactors** to maximize the yield and increase the speed of production. For example, the production of lactose-free milk has helped many sufferers overcome their lactose intolerance and enjoy dairy products.



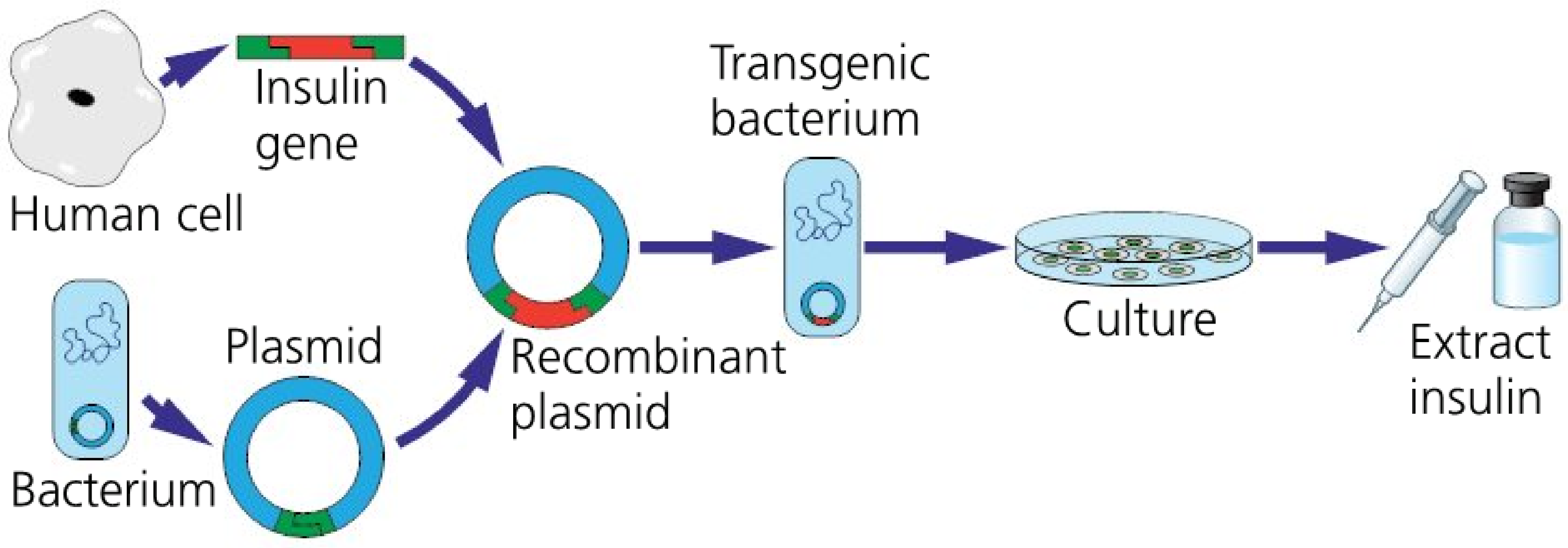
■ **Figure 2.5a** Laboratory-scale production of lactose-free milk



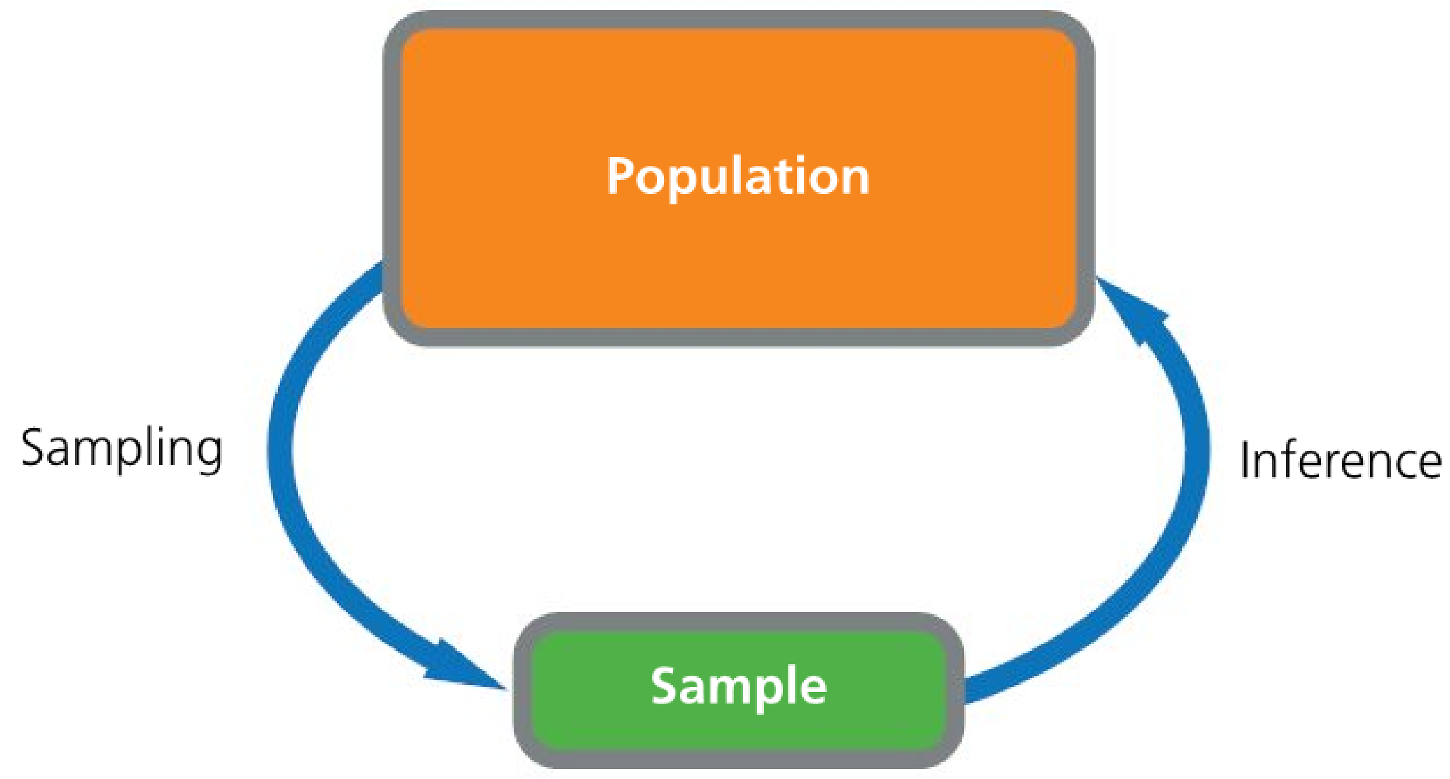
■ **Figure 2.5b** A bioreactor producing large-scale lactose-free milk

Production of insulin happens in the same way by scaling up from laboratory-scale products to commercial use. Modified **bacteria** that have been **genetically engineered** to produce human insulin are grown at large scale and the insulin protein is purified and sold commercially to help many diabetic patients worldwide.

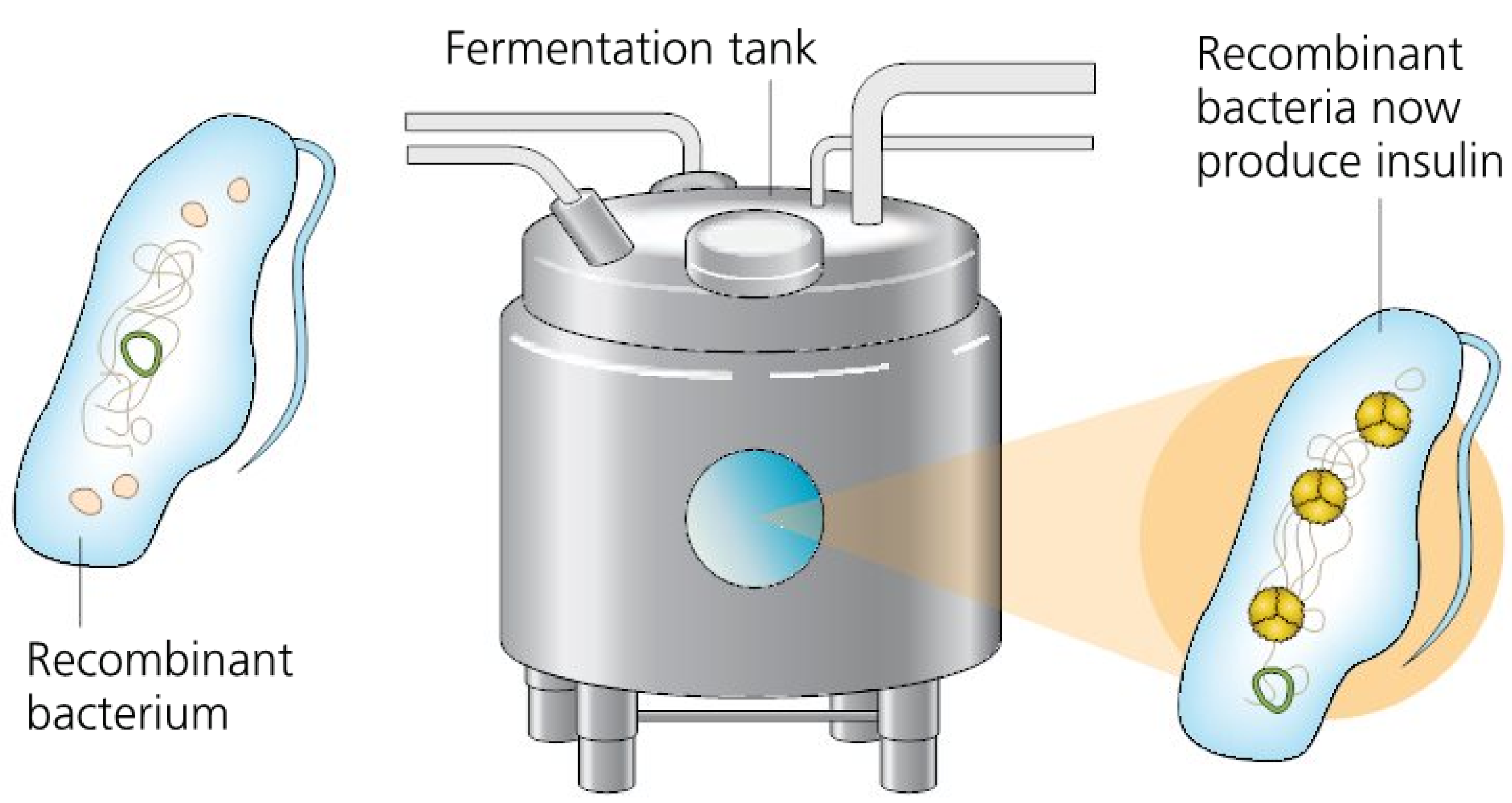
Scaling down is just as important as scaling up. Sometimes there are processes which cannot be explored at their natural size and need to be looked at with a smaller scale to give an indication of what happens in the larger sample size. In ecology, for example, this concept is used very often to estimate population size. This is called **sampling**, where small samples of a whole are analysed as an indication of what happens in the full population. It would be nearly impossible to count every single individual of a species in the area of interest, but taking random samples in different areas will give a fair indication of the natural distribution of the species.



■ **Figure 2.6a** Production of human insulin



■ **Figure 2.7** Sampling



■ **Figure 2.6b** Growing these genetically modified bacteria at large scale in fermenters for commercial production

■ **Figure 2.8** Quadrat sampling in ecology

How are living organisms structured?

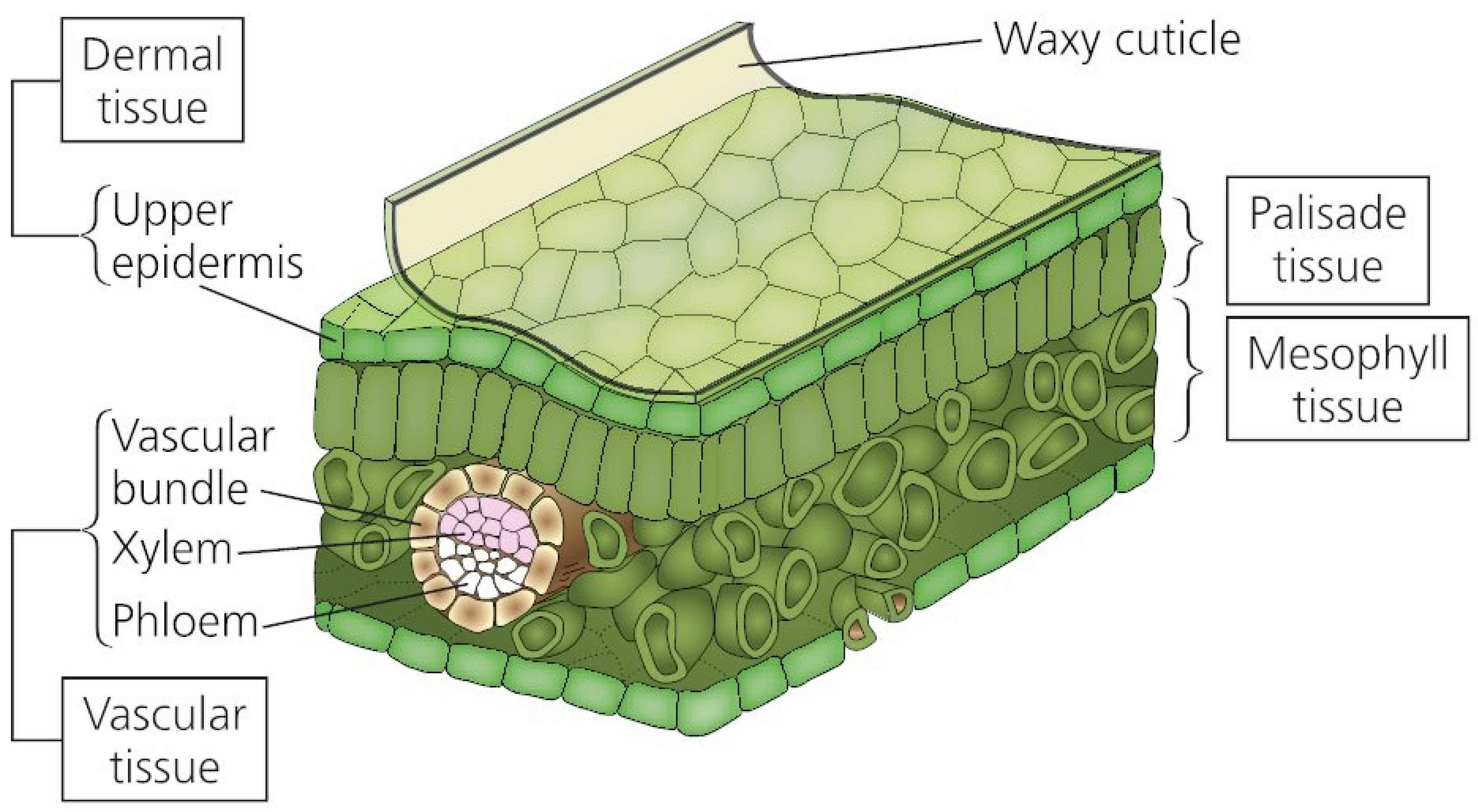
SEE–THINK–WONDER

Visit this website to see a diagram that shows the relative scale of some biological molecules and structures: **www.nature.com/scitable/content/the-relative-scale-of-biological-molecules-and-14704956**

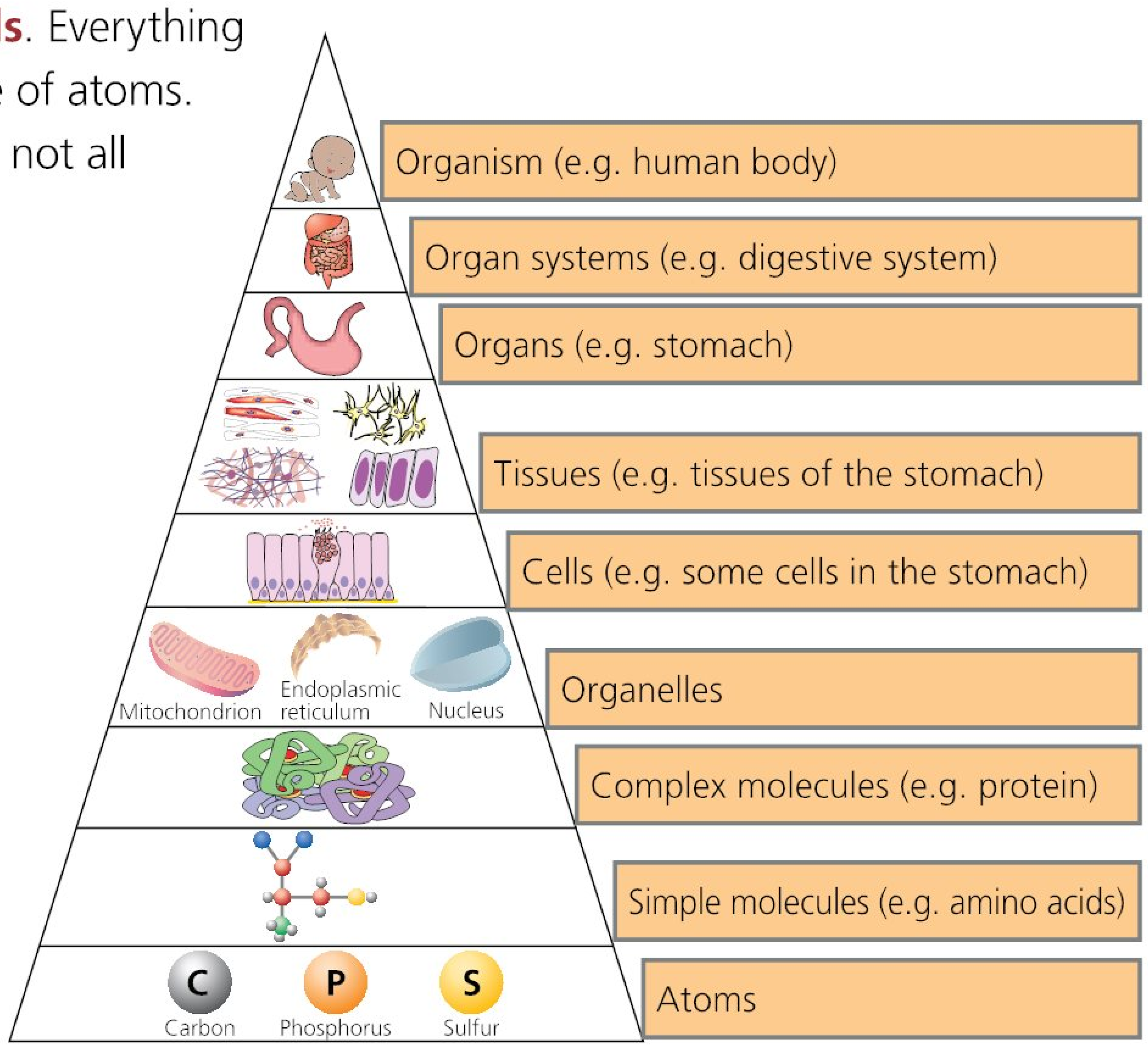
What do you **see**? What does it make you **think** about? What does it make you **wonder**?

Use scientific language to discuss the scale of the biological molecules and structures in the image.

Multicellular living organisms are usually made of organ systems that comprise various organs working together. Each organ is made of multiple tissues which are made of different smaller building blocks called **specialized cells**. Everything that is inside the cells is made of chemicals that in turn are made of atoms. Note, however, that not all living organisms are multicellular and not all multicellular organisms have this structural organization.



■ **Figure 2.9** The structural organization in a leaf showing various tissues



■ **Figure 2.10** Structural organization in the human body

Plants have a comparable structural organization to that of animals; they also have organs like roots, stems, leaves and flowers which are responsible for many functions like reproduction, food production and absorption. These organs are made of several tissue types like vascular, epidermal, parenchymal and meristem tissues. Just like in animals, these tissues are made up of numerous specialized cells (like palisade cells, cells of the phloem and xylem vessels and guard cells) that give them specific properties. A leaf, for example, is made of palisade tissue to perform photosynthesis, mesophyll tissue to allow gas exchange, vascular tissues consisting of phloem to transport sucrose around the plant and xylem to transport water from the roots to the leaves.

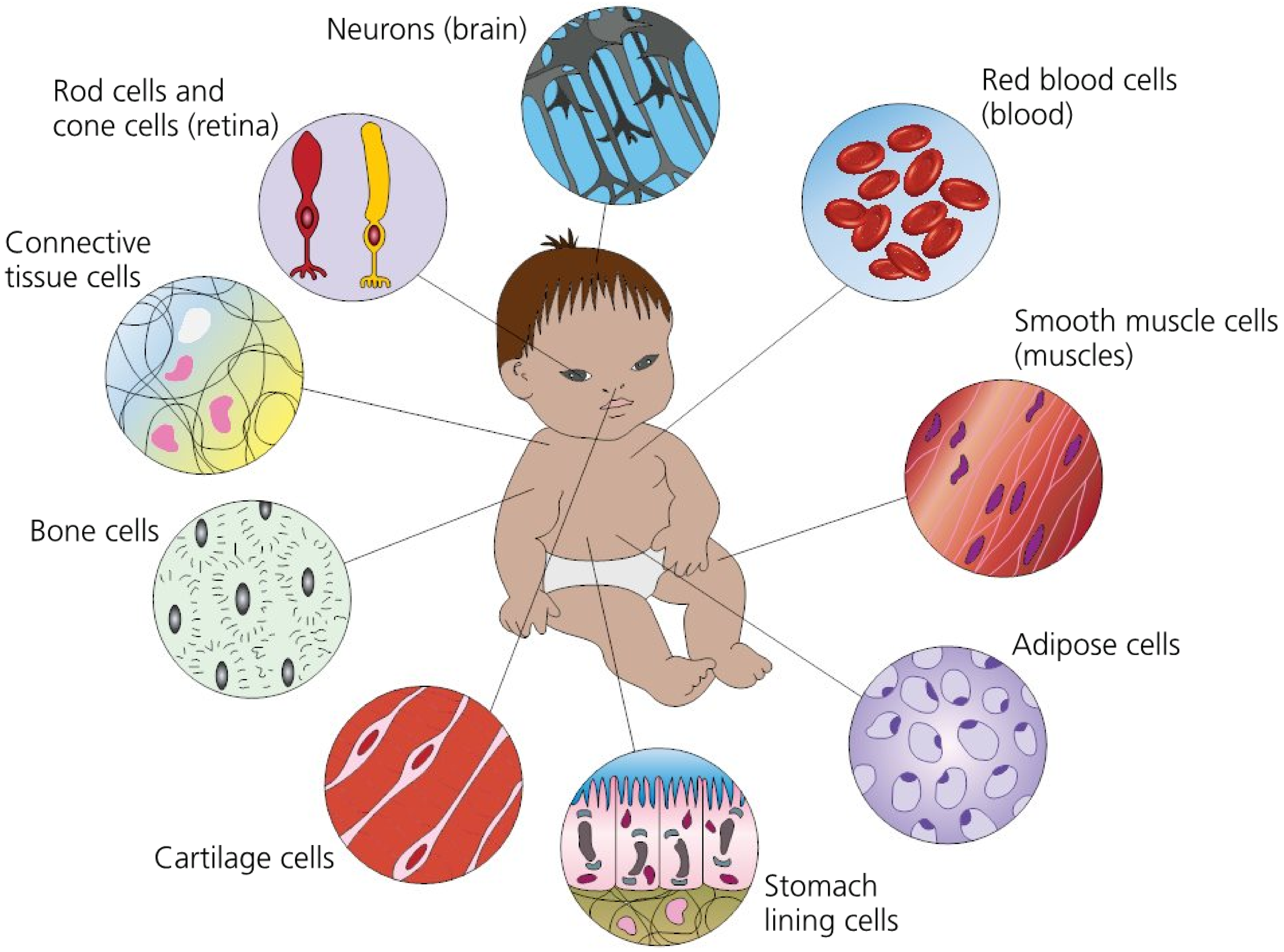
WHAT MAKES YOU SAY THAT?

Look at the structural organization of a leaf (Figure 2.9) and find corresponding organs or organ systems in humans with similar functions (Figure 2.10).

Which organ in humans is comparable to the dermal tissue? What makes you say that?

Which organ in humans is comparable to the mesophyll tissue? What makes you say that?

Which organ in humans is comparable to the vascular tissue? What makes you say that?



■ **Figure 2.11** The location of some specialized cells in the body

DISCUSS

Is each organ made of the same cell type? Which organ system has the largest number of organs working together? Which organ system has the fewest number of organs working together? Which organ has the greatest diversity of cells? And which organ has the least diversity of cell types? Can you identify other organ systems that must work together in order to function?

In humans, each **organ system** is made of a group of interacting organs that work together to form complex functional physiological systems which allow the body to perform specific functions. For example, the digestive system breaks down the food into nutrients that our body needs. Most organ systems work in synergy with other organ systems in order to fulfil their functions. The circulatory and nervous systems, for instance, work with all other organ systems to help them complete their actions. The **organs** of any organ system are fully differentiated parts of the body which are responsible for a specific function. For example, the stomach is only responsible for mechanical and chemical digestion of food and it cannot help the body to breathe or load the blood with oxygen; this is a function of another organ, the lung. Organs gain their functions from the various **tissues** that make them up. To take one example, the stomach has various tissues that work together to allow it to complete its digestive function: muscle tissue, epithelial tissue, secretory glands and connective tissue. Each tissue is again made of different types of specialized cells with a common origin, structure and function that work together to give the tissue its properties. For example, specialized cells in the blood like macrophages, lymphocytes and monocytes differentiate from **hematopoietic stem cells** to work together and give the blood its properties. Cells in a healthy tissue divide to replace dead ones and so maintain the function of the tissue. Sometimes cells start dividing uncontrollably and this can cause overgrowth and may lead to tumours.

ACTIVITY: How are we structured to function as well as we do?

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument; Revise understanding based on new information and evidence

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

Think of all the functions you can do and find what organized structures in your body are responsible for the function. Find the organ system then zoom in and find out what organs, tissues and specialized cells are involved. Conduct some research and complete Table 2.2 following the example row.

I can do this …	What helps me do it? (organ system)	How does it work? (organs)	What is it made of? (tissues)	What gives it its properties? (some specialized cell types)
eat many foods to sustain myself	digestive system	• alimentary canal organs: mouth, oesophagus, stomach, small and large intestines • accessory organs: salivary glands, liver, pancreas, gallbladder	epithelial, connective, muscle and nervous	various epithelial cells, including secretory cells for glands, endothelial, hepatic, Kupffer, muscle and nerve cells

Table 2.2 What makes our organ systems?

HOW CAN CELLS SUSTAIN THEMSELVES?

ACTIVITY: Equip a cell!

ATL

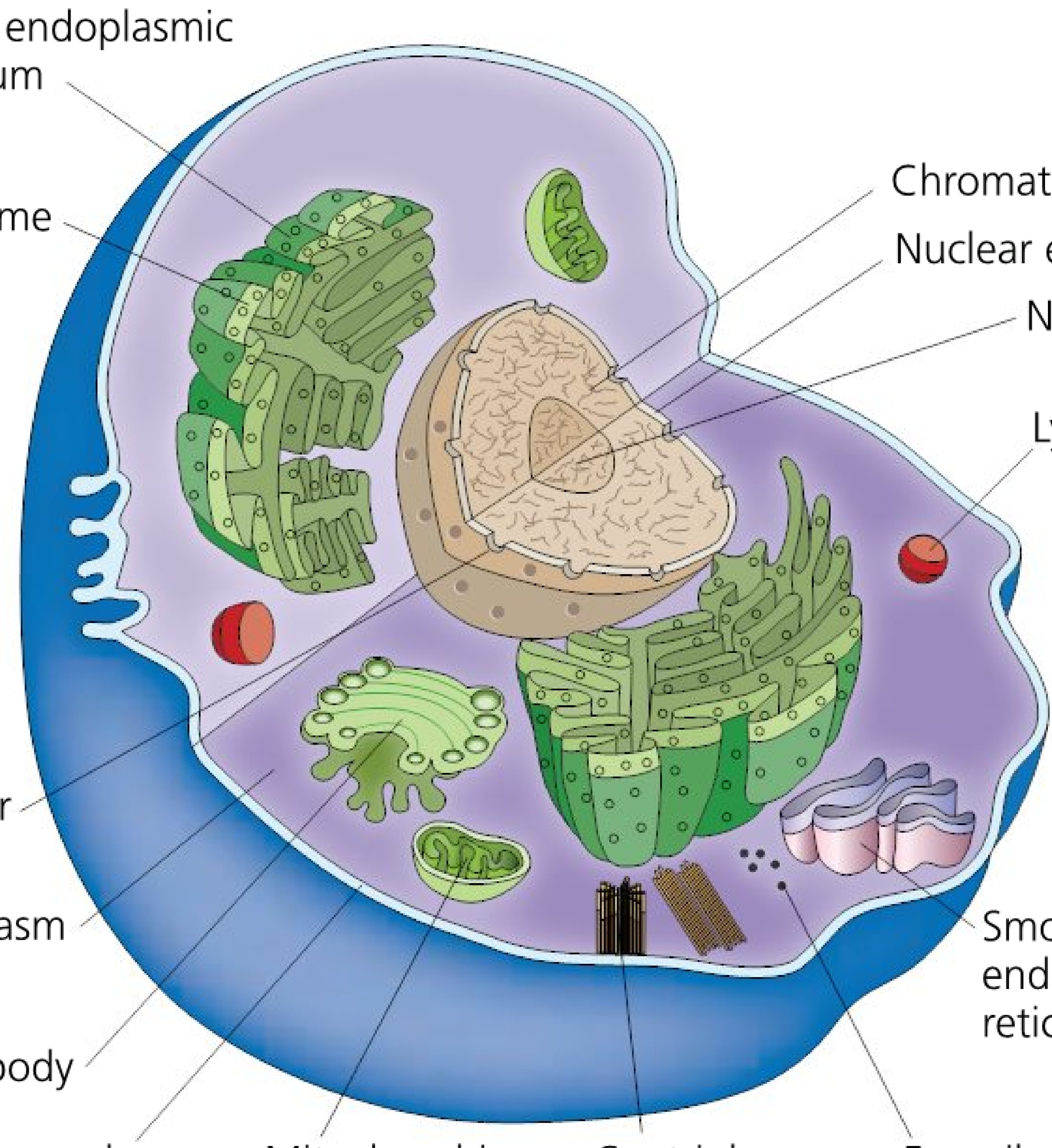
- Information literacy skills: Access information to be informed and inform others
- Critical-thinking skills: Use models and simulations to explore complex systems

We can understand the way that organelles work together to form a cell by thinking of a house analogy. In this activity you will build a model cell taking into account what a cell needs to sustain itself. How would you equip a newly built house? What facilities would you have to source from the outside and how would you divide the rooms for different functions? How does this compare to a cell? Would a cell need to source things from outside? Would it need compartments for different functions?

One way to approach this task is to think of a problem posed by a need for a function in the cell, then try to solve it by finding the organelle that is responsible for it. Use the following search terms to guide you: **functions of life, cell structure**. Use the empty house analogy to help you equip your cell. You can complete this activity on a poster made by hand or using software, or by making a 3D model using modelling clay or cardboard boxes, for example. Write a short description of your model including the type of cell and its functions then present your model to the class and receive feedback from your peers.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion D: Reflecting on the impacts of science.



■ **Figure 2.12** Organelles of an animal cell

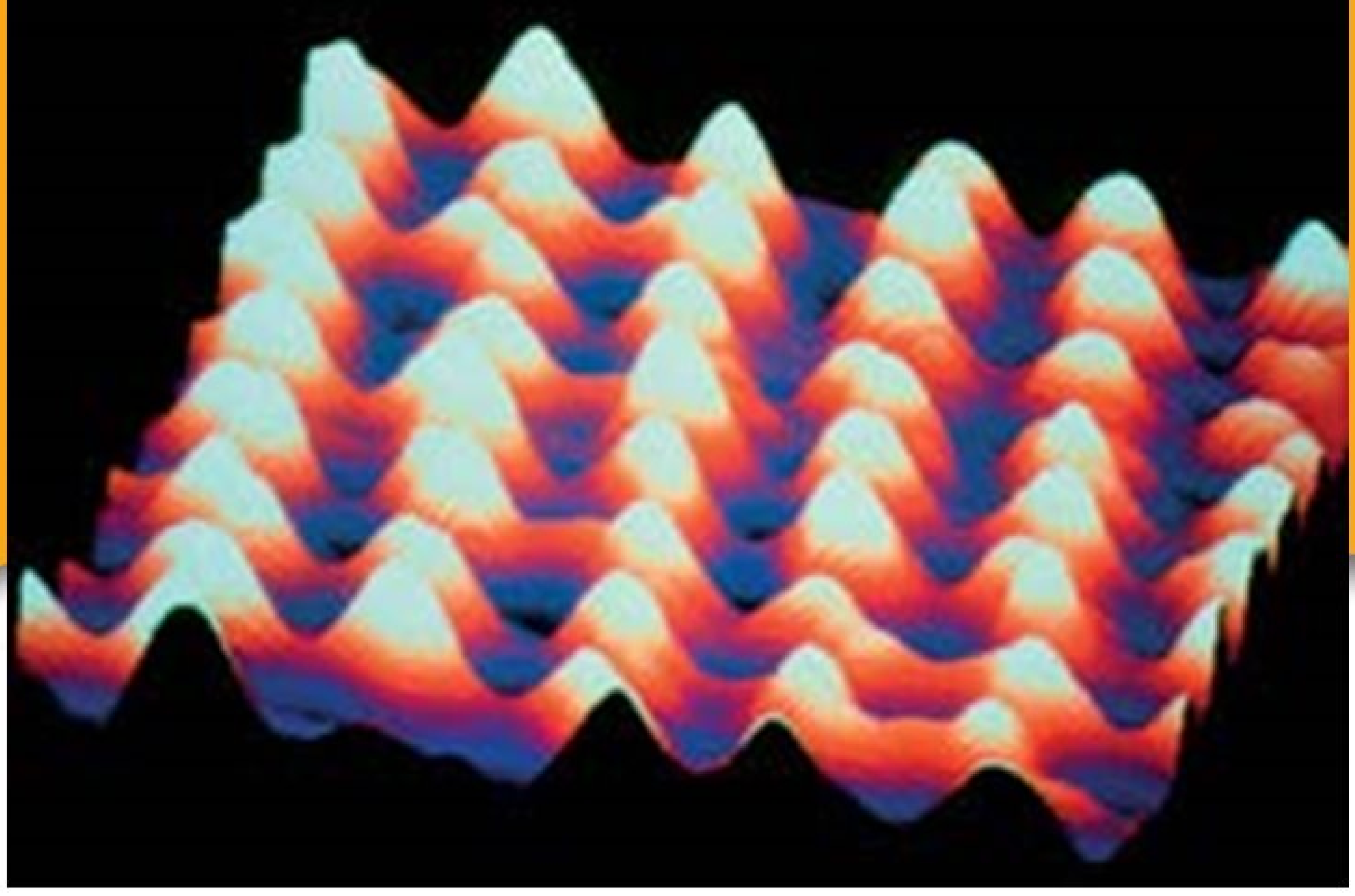
If we zoom in further inside cells we find compartments called **organelles**. However, the organelles alone would not be able to build living organisms. They must work together in an orchestrated manner to create a small sustainable block that acquires new characteristics, which then can act as a building block for more complex structures.

Each cell is isolated from the outside environment by a flexible plasma membrane that contains areas for entry and exit of materials to and from the cytoplasm. The cytoplasm provides the water needed for metabolic reactions to occur. The heritable genetic information that determines the shape and functions of the cell is packed in DNA and organized in chromosomes packaged in a designated area in the cytoplasm. **Prokaryotes** package their DNA in a designated location in the cytoplasm called a **nucleoid**, while **eukaryotes** package it in a nucleus. Proteins, which perform necessary functions in the cells, are made in the ribosomes from the code received from the nucleus. These proteins are sent inside **secretory vesicles** to the Golgi apparatus where they are modified and packaged before being transported or secreted outside the cell. The cell is always active and therefore needs energy which it produces in the mitochondria (in the form of **ATP**) by breaking down nutrients like glucose through the process of cellular respiration. Such metabolic reactions generate waste products which can be toxic to the cell. Therefore they need to be secreted outside the cell through the plasma membrane or get destroyed inside **lysosomes** which contain digestive enzymes.

EXACTLY HOW SMALL IS AN ATOM?

No doubt you will have realized by now that atoms are extremely small. Maybe you have even been presented with statistics like 'there are 500 000 carbon atoms lined up in the width of a hair' or that 'one sheet of paper is about 500 000 atoms thick' or 'there are more atoms in a glass of water than there are glasses of water in all the world's oceans'.

But how small is small? To attempt to understand the atomic scale it helps to put the size of an atom in a context that we are better able to understand. How does that then change our understanding of the objects and living things around us?



■ **Figure 2.14** A scanning tunnelling microscope image of the two-atom-thick lead film

SEEING IS BELIEVING

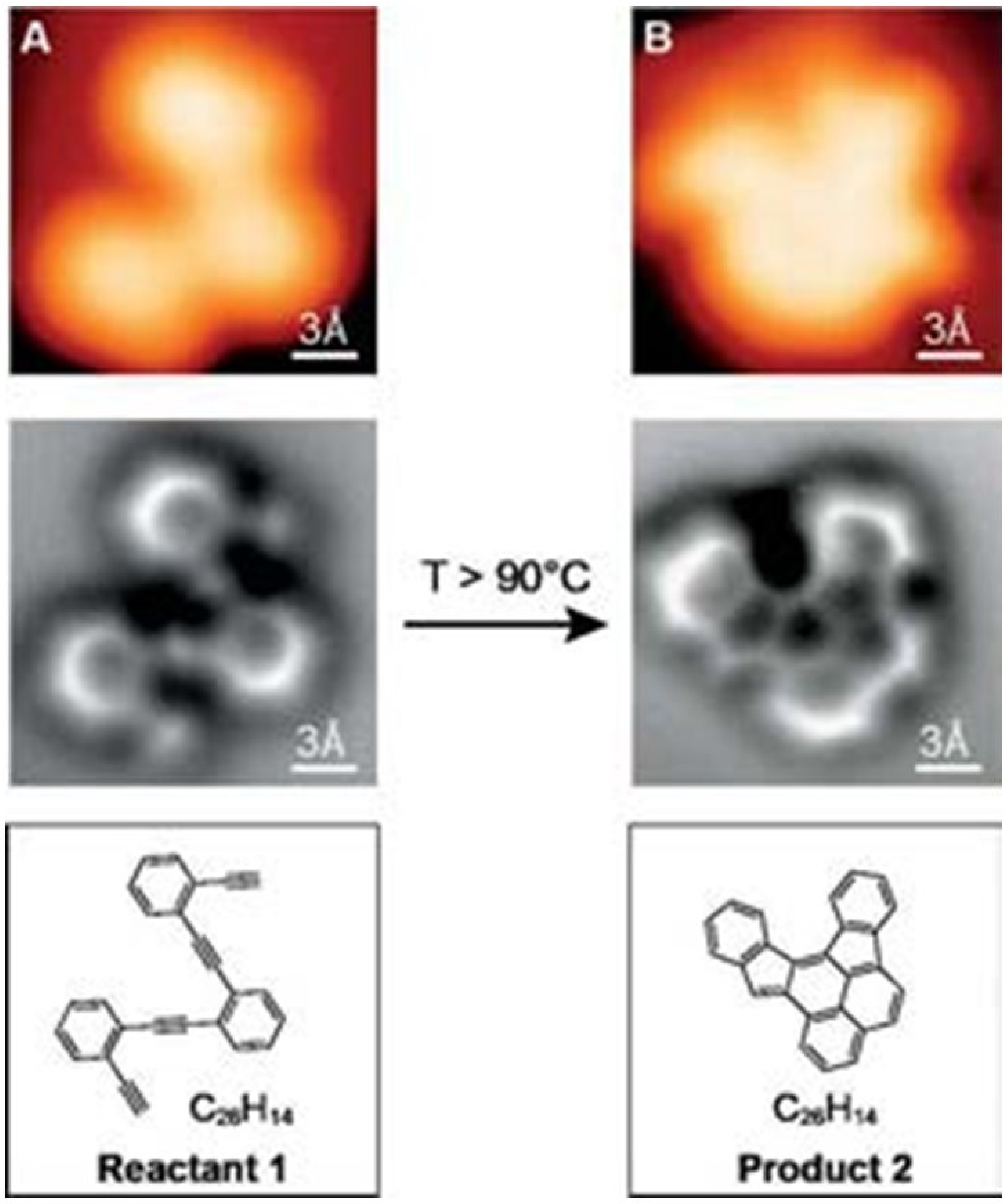
The tiny size of atoms has been the greatest obstacle to discovering ways to 'see' them. As we saw earlier in this chapter, this is impossible to do under even the most powerful light microscopes, which are only able to magnify objects that are larger than the wavelength of visible light; a typical atom is more than 10 000 times smaller. Our understanding of atoms, molecules and compounds started to change in the 1890s when X-rays were discovered. This led to a technique called X-ray diffraction or X-ray crystallography and, because of it, scientists were able to measure the size of atoms, the length of bonds and determine the structure of a huge range of materials.

■ **Figure 2.13** An X-ray crystallography machine; a crystal is held in place between a screen and a device which gives out X-rays

Developments in technology led to the creation of electron microscopes, in which a beam of electrons rather than a beam of light is shone at the sample. In the early 1980s, scientists were finally able to study the structure of the surface of an object, atom by atom, with the discovery of the scanning tunnelling microscope (STM).

Through both STM, and more recently atomic force microscopy (AFM), scientists have been able see and manipulate materials at their most fundamental scale: the atomic scale. An STM is able to pick up individual atoms one at a time and move them to create some of the smallest structures imaginable, which is necessary for the field of **nanotechnology** which deals with objects on a nanoscale.

The implications of being able to rearrange atoms on the surface of substances reach far and wide. Can we rearrange the atoms in charcoal to form diamonds? Can we use atoms of carbon, hydrogen and oxygen to create food?



■ **Figure 2.15** In 2013, scientists were able to capture (A) 'before' and (B) 'after' images of chemical reactions using non-contact atomic force microscopy

Using models

In this activity we will use a model to better understand the structure of the atom. The scales we use in science range from the very, very small to the very, very large, often making it impossible to physically see the objects we are studying. Models are, therefore, an extremely useful tool, allowing us to create a visual image of the object and making it easier to remember. As our understanding of science changes, models can be adapted to reflect changes in our theories.

WHAT IS AN ATOM?

ACTIVITY: Build an atom

ATL

- Critical-thinking skills: Use models and simulations to explore complex systems and issues
- Reflection skills: Develop new skills, strategies and techniques for effective learning

In this activity you will be building your own atoms using a simulation and exploring some of the features of the different sub-atomic particles. Some of this may already be familiar to you, some of it may be new, but use the activity to consolidate what you already know about the atom and build on your existing knowledge. Start by familiarizing yourself with the simulation you will be using.

- **Go to the following website: http://phet.colorado.edu/en/simulation/build-an-atom**
- **Press the 'Play' button to start the programme (you may need to download it first).**
- **Select the simulation called 'Atom'.**
- **Press the '+' next to 'Net Charge' and 'Mass Number' to maximize the two menus.**
- **Tick the box next to 'Stable/unstable' in the 'Show' section.**
- **Make sure your model is set to 'Orbits' not 'Cloud'.**
- **Become familiar with the controls and functions of the simulation by dragging the sub-atomic particles into and out of your atom. Observe what happens to the stability of the atom and its charge as you add and remove the different sub-atomic particles.**

When you feel you are ready to start the exercise, press the 'Reset All' button in the bottom right-hand corner. Answer the following questions, using the simulation to help you.

1. **State which sub-atomic particles are present in the nucleus and which are not. Where are the latter located?**
2. **State which particles have a charge and identify their respective charges.**
3. **State which is the only sub-atomic particle that determines the type of atom (the element it is).**
4. **State the maximum number of electrons that can exist in the first 'orbit' (this is the shell or energy level).**
5. **State the maximum number of electrons that can exist in the second orbit.**
6. **Describe how you would create a neutral atom and give an example of one that you have created, stating how many of each sub-atomic particle is present.**
7. **Describe how you would create a stable atom and give an example of one that you have created, as well as an example of an unstable atom of the same element, stating how many of each sub-atomic particle is present in each.**
8. **Create three neutral, stable atoms, selecting any elements from hydrogen to neon in the periodic table. In each case identify the following information: number of protons, number of electrons and number of neutrons, all of which are provided in the top left-hand corner of the simulation screen. Identify the total mass of the atom (called the mass number and given in the 'Mass Number' box).**
9. **Suggest a relationship between the number of protons and number of electrons.**
10. **Suggest a mathematical equation for working out the number of neutrons in an element.**
11. **Evaluate your suggestions by testing them with two elements that cannot be created on the simulation. Work out how many protons, electrons and neutrons they should have and then check by researching it.**

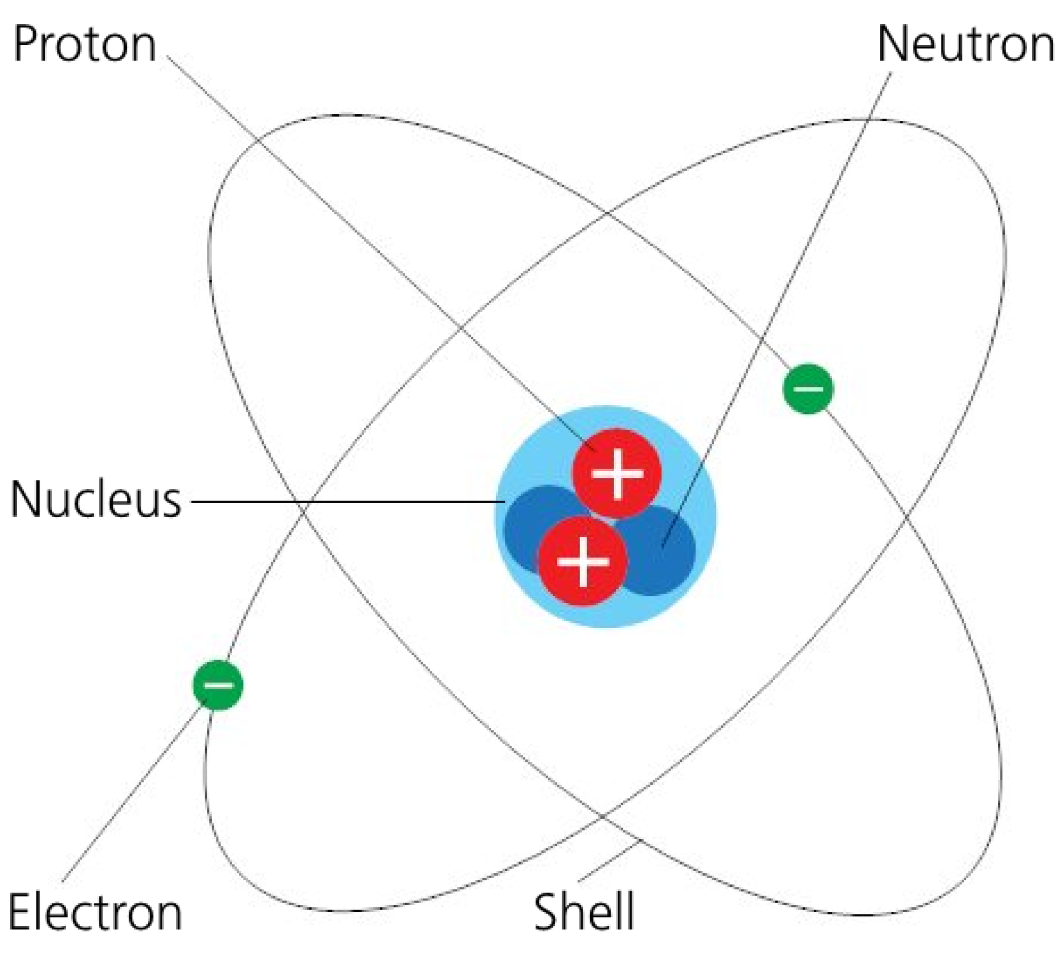
Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

Sub-atomic particle	Mass/kg	Mass (relative to proton)	Relative electrical charge
proton	1.6726×10^{-27}	1	+1
neutron	1.6749×10^{-27}	1	0
electron	9.1094×10^{-31}	0 (negligible)	−1

■ **Table 2.3** Summary of the masses and charges of the sub-atomic particles in an atom

From individual molecules, to human beings, to stars, everything is made of atoms. So what is an atom? Figure 2.16 shows the structure of an atom. An atom is a particle that consists of a central nucleus, which contains protons and neutrons, and electrons, which orbit the nucleus in **shells** (also known as **orbits** or **energy levels**). Protons, neutrons and electrons are called sub-atomic particles. The masses and charges of these sub-atomic particles are shown in Table 2.3.



■ **Figure 2.16** The structure of an atom

The number of protons in an atom is called the **proton number** or atomic number, and can be represented by the symbol Z. You will have noticed in the *Build an atom* activity that, as you changed the number of protons, you changed the type of substance or the element. This is because the number of protons in the nucleus of an atom is unique to a particular element. The proton number or atomic number of an element also represents its position in the periodic table; for example an element with 13 protons will also be the 13th element in the periodic table. There will be more about this in Chapter 3.

All atoms are neutral which means that they have no overall electric charge. Protons and electrons carry the same quantity of electric charge:

$$e = 1.6 \times 10^{-19} \text{ coulombs}$$

but with an opposite sign; their relative charges are often denoted as $+1e$ and $-1e$, respectively. For a neutral atom, the number of protons must be equal to the number of electrons as the positive charge in the nucleus is cancelled out by the negative charge of all the orbiting electrons. Neutrons do not contribute any charge to the atom.

The mass of a proton and that of a neutron is very similar, and the average mass of the nucleons is known as the **unified atomic mass unit** (u) where

$$u = 1.7 \times 10^{-27}\,\text{kg}$$

Electrons are almost 2000 times lighter than these and are regarded as having a **negligible** mass. This means that the effective total mass of an atom lies in the nucleus and will be equal to the mass of the protons and the mass of the neutrons. The total mass of an atom expressed in atomic mass units is known as the **mass number** or **nucleon number** (and can be represented by the letter A).

mass number (A) = number of protons (Z) + number of neutrons (N)

EXPLANATION GAME

I notice that number of electrons = number of protons. Why is it that way?

I notice that mass number = number of protons + number of neutrons. Why is it that way?

I notice that number of neutrons = mass number – proton number. Why is it that way?

ELECTRON ARRANGEMENTS AND ELECTRON SHELL DIAGRAMS

The distribution of the electrons in the shells is fundamental to understanding the chemistry of the elements. Electrons fill their shells in order, starting with the one closest to the nucleus, because the energy of the shells increases with increasing distance from the nucleus. However, depending on how close to the nucleus a shell is, its size will vary, which in turn affects the number of electrons that it can hold.

The **electron arrangement** (also known as **electronic structure** or **electronic configuration**) describes the arrangement of the electrons in the shells. This is a series of numbers showing the total number of electrons in each shell, with each number separated by a comma. You need to be able to deduce the electron arrangement of the first 20 elements. The following tips will help you.

- You start by populating the shell closest to the nucleus.
- The first shell can hold up to two electrons.
- The second shell can hold eight electrons.
- The third and fourth shells can hold 18 and 32 electrons, respectively. However, at this level, you can regard them as 'filled' when they contain eight electrons (the reasoning for which you will discover when you study IB Diploma Chemistry).

Here are some examples of electron arrangements/electronic configurations:

- helium (Z = 2): 2
- carbon (Z = 6): 2,4
- potassium (Z = 19): 2,8,8,1.

The electron arrangement of an atom can also be shown diagrammatically. These are known as **electron shell diagrams**. Figure 2.17 shows the electron shell diagram for an atom of sodium and an atom of sulfur.

So how 'accurate' is our atomic model? We have already seen that the number of electrons in the third shell onwards isn't eight, but it is also worth noting that the shells are not always completely filled before occupying the next energy level and they are not really concentric rings at a fixed distance from the nucleus. Further, this model does not represent accurately how small the nucleus is compared to the rest of the atom and that the atom consists mainly of empty space. Our model is, therefore, an approximation that helps us explain the way things are for the moment, but which we will need to elaborate later as we learn more about atomic structure.

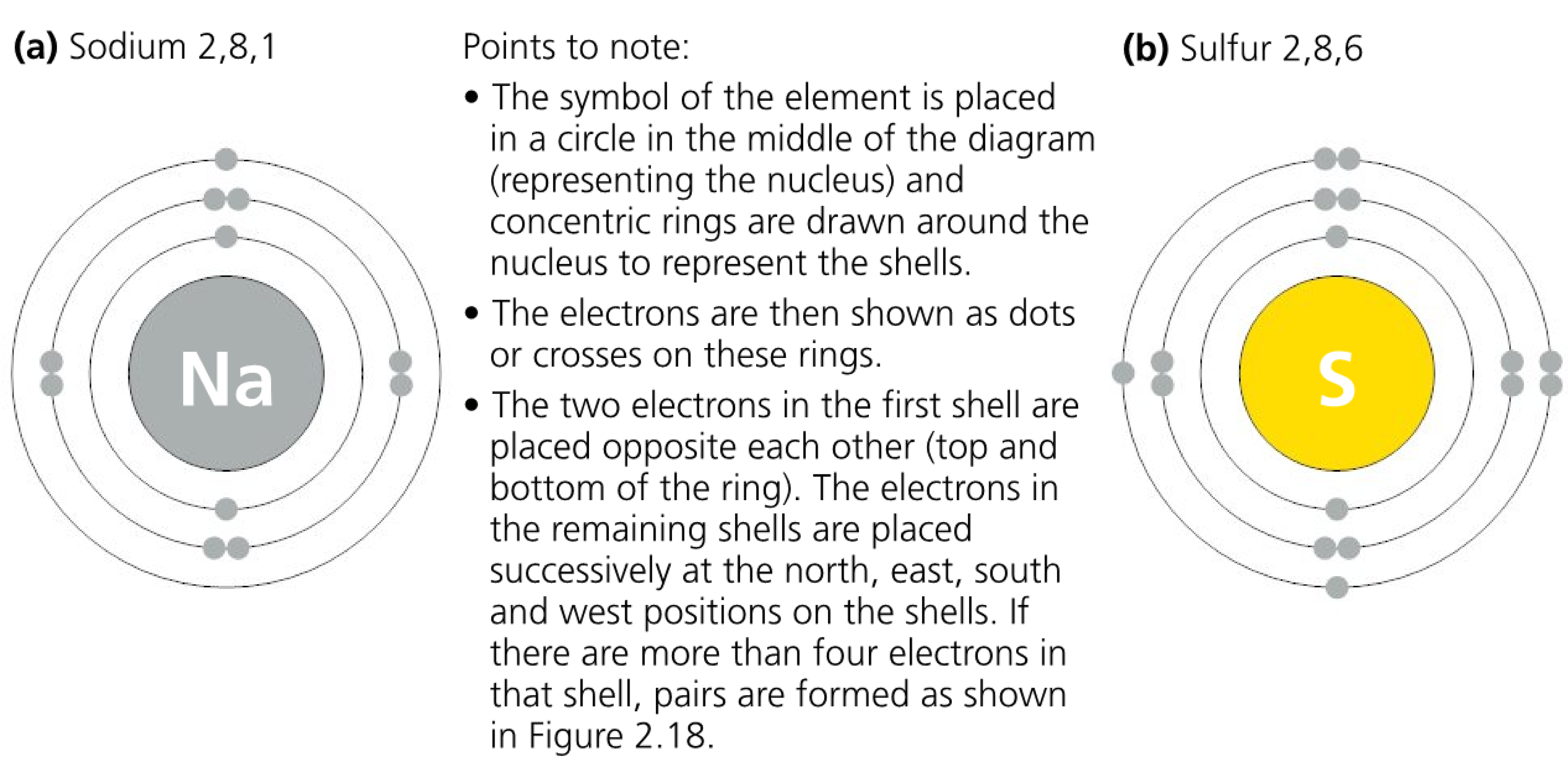


Figure 2.17 Electron shell diagram for an atom of (a) sodium and (b) sulfur

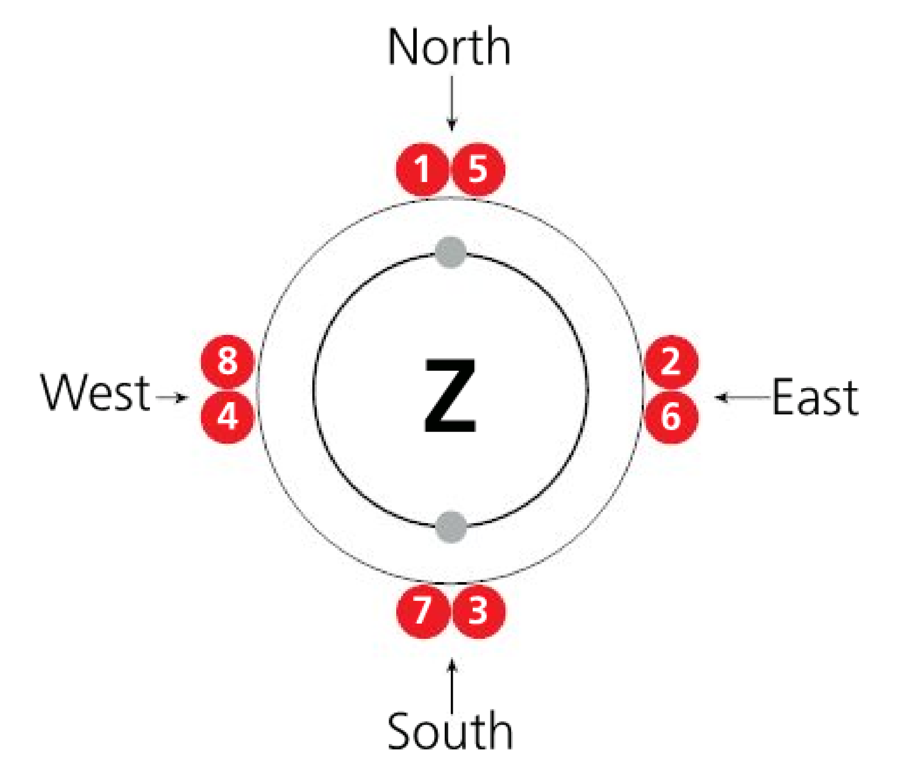


Figure 2.18 How to allocate electrons to the second, third and fourth shells

ACTIVITY: Make an electron shell diagram display

ATL

- Collaboration skills: Help others to succeed; Take responsibility for one's own actions; Give and receive meaningful feedback

Materials

- **A periodic table**
- **20 A4 sheets of paper (white or coloured)**
- **Permanent pens**
- **Polystyrene balls (about 250, with a diameter of 1–2 cm)**
- **Glue**

Method

The aim of this activity is to create a display of the electron arrangements and electron shell diagrams for the first 20 elements of the periodic table.

1. **In your notes, list the names and corresponding symbols of the first 20 elements in the order that they appear in the periodic table.**
2. **Deduce the electron arrangement of each element.**
3. **Select one of the elements and on an A4 sheet of paper in the landscape position state the element name, symbol and electron arrangement in the top right-hand corner.**
4. **Construct an electron shell diagram of the element, using polystyrene balls to represent the electrons and sticking them into their respective positions. Include the element symbol and place the electrons in the right positions by referring to Figure 2.18.**
5. **When you have finished, select a different element until the class has created models for all 20 elements.**
6. **Peer assess each other's work, double checking the symbol and electron arrangement, counting the total number of electrons represented in the electron shell diagram and ensuring that the electrons have been placed in the correct positions.**
7. **Display your models in your classroom or on a wall outside a science lab.**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

ACTIVITY: Scale it up!

ATL

- Critical-thinking skills: Revise understanding based on new information and evidence; Use models and simulations to explore complex systems and issues; Identify obstacles and challenges

You have been invited to give a TED Talk on the topic of 'Using models in science'. For this task, you will create a script of the talk as well as a short video. You will be completing this task in groups of three and your audience will be other students your age.

The aim of your talk, 'Using models in science', is to explain the way in which science has been applied to address the problem of not being able to see atoms. Ensure your script makes reference to the following:

- **Describe why we create and use models of objects that are either too big or too small to see. Give examples, other than the atom, of where you have used models before in science.**
- **Analyse the advantages and disadvantages of using models.**
- **Evaluate whether these models help or hinder your understanding of scientific concepts.**

The aim of your video is to provide a more realistic model of the structure of an atom than that which appears in textbooks, using the analogy in the TED Talk video on page 33. This stated that if the nucleus was the size of a marble, the atom would be the size of a football stadium. You will need to select an area that is large enough to achieve this, so the video may need to be created in your own time at a park. Once you have determined by calculation the exact size of your model atom, have one member of your group represent the nucleus and one member represent hydrogen's lone electron in the first shell. The third member will be responsible for filming. Consider different ways to present the video; will you use a time-lapse of the 'electron' walking away from the 'nucleus'; will the 'nucleus' and the 'electron' try to communicate?

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion D: Reflecting on the impacts of science.

I USED TO THINK …
NOW I THINK …

Watch this TED video for an alternative view of the atom: **www.ted.com/talks/just_how_small_is_an_atom**

Reflect on how the video has changed your thinking about the size of an atom and the size of the sub-atomic particles within it, comparing them to the size of the atom itself, by completing the following sentences:

I used to think …

Now I think …

HOW WAS THE STRUCTURE OF THE ATOM DISCOVERED?

The models created by scientists to understand the structure of the atom required creativity and imagination, as well as a critical approach by the scientific community, who must not accept scientific claims without adequate reason or evidence (as we saw in Chapter 1). The model of the atom that we use today is a great example of this; it is the result of the work of a number of scientists over hundreds of years, whose theories were not necessarily accepted immediately. You may have encountered some of these thinkers and their ideas in *MYP Sciences by Concept 2*, and in the activity *Unfolding the mystery of the atom* you will have an opportunity to review and synthesize this information.

The focus of this chapter so far has been on individual atoms: the structure of an atom; the atom of an element. But why focus on understanding something so small we cannot see it and that we will never come across in our everyday lives? Nothing we use and no living things are made of a single atom. To connect the properties of materials we encounter every day, we need to consider the ways in which atoms can form groups, such as those that form the copper wire we need for the conduction of electricity, or those that form the genetic material in our cells. Understanding the structure of an atom and the properties of the sub-atomic particles is fundamental to explaining how and why atoms bond to each other and the types of bonds they form. It is these bonds, formed at the atomic level, that allow structures to build up from single individual atoms to the billions and billions of atoms that comprise the everyday objects we use and that make up the parts of living organisms.

ACTIVITY: Unfolding the mystery of the atom

ATL

- Information literacy skills: Present information in a variety of formats and platforms
- Communication skills: Read critically and for comprehension
- Reflection skills: Consider content

As a class, brainstorm what a storyboard is. Come up with ideas as to what it should look like and what features would make a storyboard successful.

In this task you will **create** a cartoon storyboard explaining how scientists came to discover the structure of the atom. Choose the information that you want to include in the text box part of the storyboard carefully; it needs to be concise but detailed enough to convey the key points. **Annotate** your picture; this is how you can include extra information other than what is in the text box. Your storyboard will focus on the following scientists:

- **Democritus**
- **Dalton**
- **Thomson**
- **Rutherford**
- **Bohr**
- **Chadwick.**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

To what extent does our everyday experience limit our understanding of the very small and the very large?

$$\underbrace{602}_{\text{Sextillions}}\ \underbrace{200}_{\text{Quintillions}}\ \underbrace{000}_{\text{Quadrillions}}\ \underbrace{000}_{\text{Trillions}}\ \underbrace{000}_{\text{Billions}}\ \underbrace{000}_{\text{Millions}}\ 000\ 000$$

■ **Figure 2.19** Avogadro's constant

As atoms are so small, it means that even tiny bits of matter are made up of a huge number of atoms. Rather than deal with these massive numbers, chemists use the term **mole** as a counting unit. One mole of a substance always has a specific number of atoms or molecules in it – specifically 6.02×10^{23}, known as **Avogadro's constant** (after the Italian scientist Amedeo Avogadro). So 1 mole of hydrogen atoms, for example, consists of 6.02×10^{23} hydrogen atoms.

Let's focus on a gold ring. An average gold ring has a mass of 10 g. One mole of gold has a mass of 197 g, which means that there are 6.02×10^{23} atoms in 197 g of gold. So how many atoms are there in a 10 g gold ring? Approximately 3×10^{22} atoms (or 30 sextillion atoms). Now that's a big number, but do we really understand how big?

ACTIVITY: Getting rich!

■ ATL

- Creative-thinking skills: Make guesses, ask 'what if' questions and generate testable hypotheses; Make unexpected or unusual connections between objects and/or ideas; Generate metaphors and analogies

We've just worked out that there are approximately 3×10^{22} gold atoms in a gold ring. Now imagine that instead of having 3×10^{22} atoms, you have 3×10^{22} one-cent coins. Now imagine that you are going to distribute these evenly to every person on Earth (assume the Earth's population is 7 billion). How much money do you think each person will end up with?

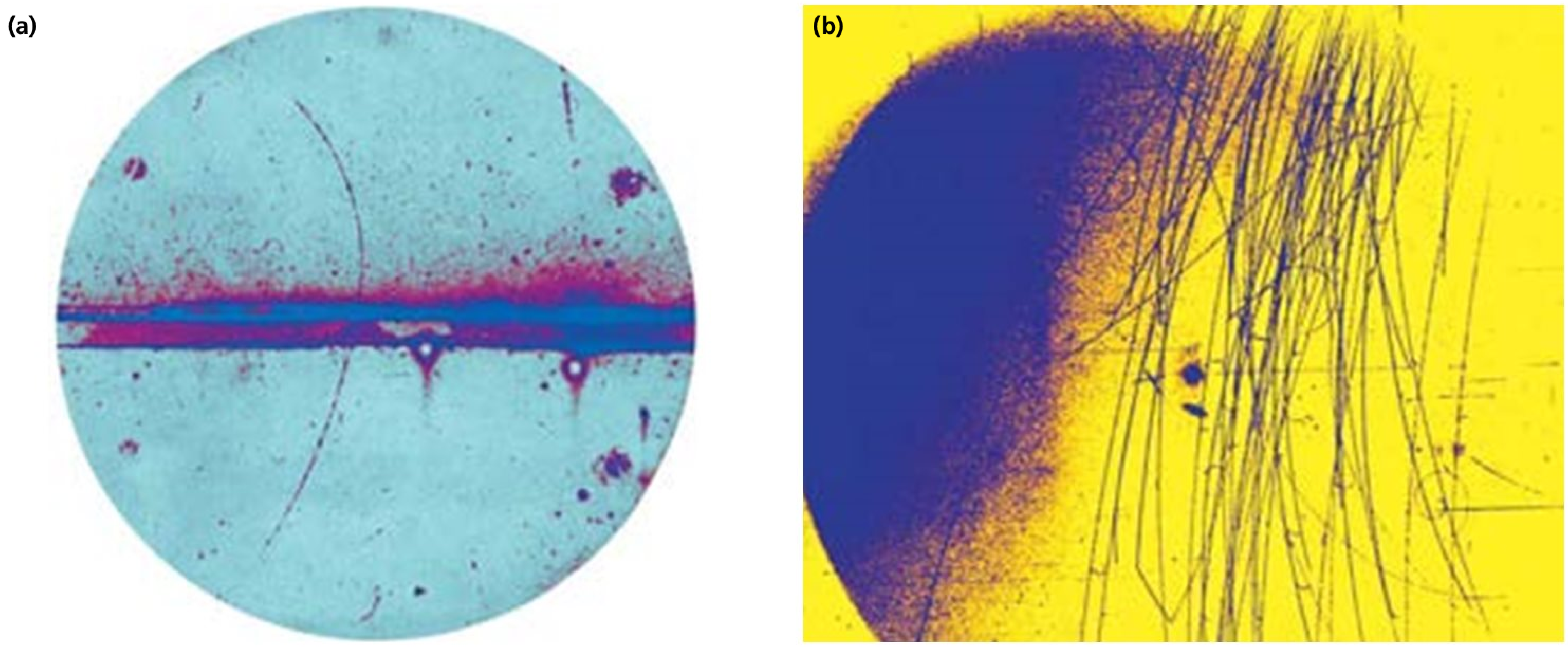
- **Make an approximate prediction: will each person get hundreds, thousands, millions, billions of dollars? More or less than these numbers?**
- **Now calculate how much money each person would get.**
- **Comment on how close your prediction was to the calculated value.**
- **Identify other contexts where you use very large or very small numbers and discuss how this activity has changed your perception of the size of these numbers.**
- **Reflect on the extent to which your everyday experience helps and/or hinders your understanding of numbers such as Avogadro's constant.**

There are many different contexts in which Avogadro's constant can be presented to try to provide a better understanding of its size. Search for **Avogadro number analogies**; find another analogy in a context that you find useful and share this with a peer.

◆ Assessment opportunities

- ◆ In this activity you have practised skills that are assessed using Criterion C: Processing and evaluating

What building blocks do scientists use to describe non-living matter?



■ **Figure 2.20** (a) Physicist Carl D. Anderson's 1932 photograph of the trace made by a positron at California Institute for Technology; (b) image of a meson decay from the Nevis (Columbia University) cyclotron, 1950s

WHAT MAKES YOU SAY THAT?

Look at the images in Figure 2.20 and read their captions.

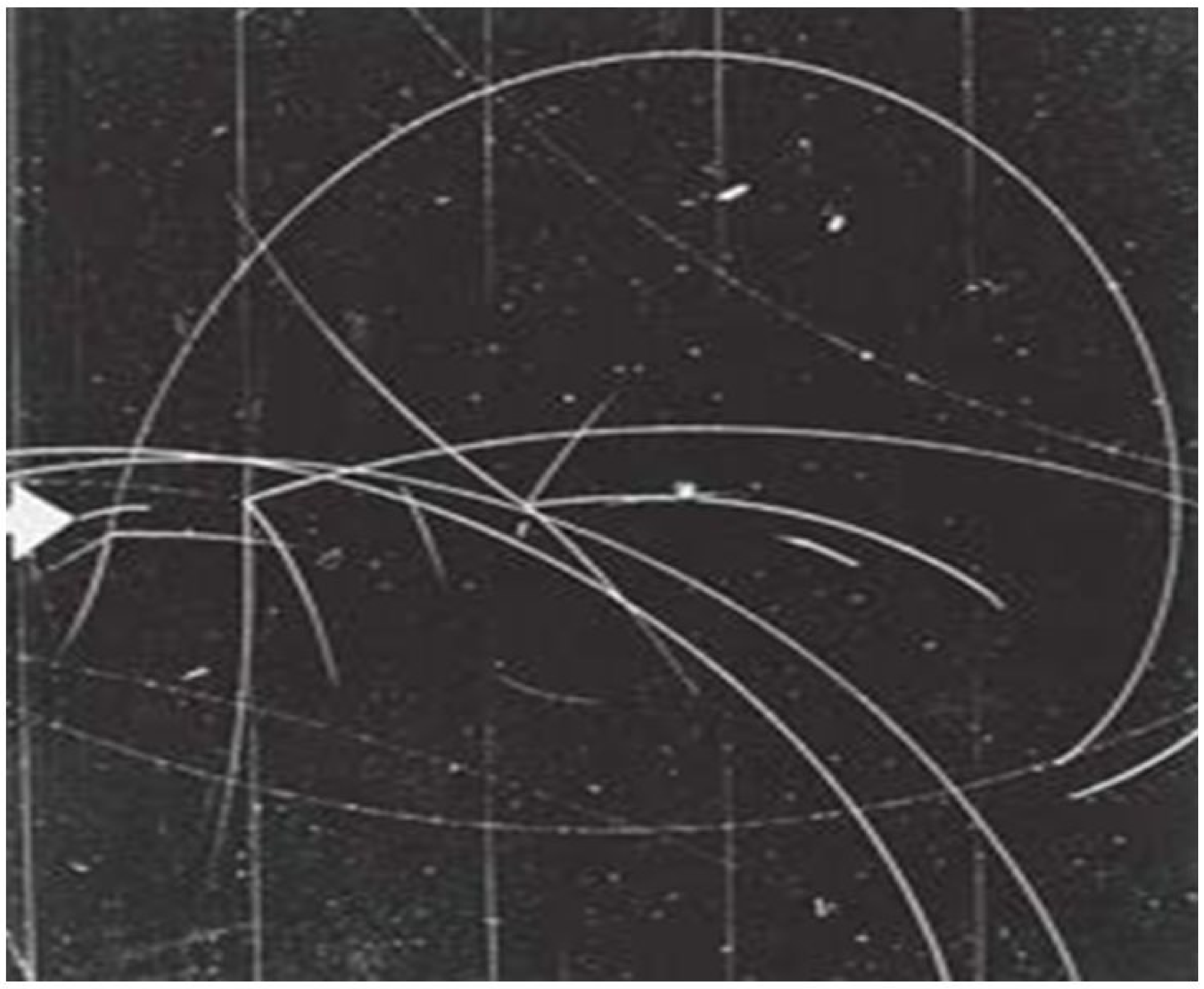
Individually, **think**: what is going on in these images?

In pairs, **discuss**: what makes you say that?

Your reaction to the images in Figure 2.20 might have been that they were works of abstract art; in fact, both these images have been used as artworks! But to a scientist their meaning is quite specific.

As you know it is barely possible to 'see' direct evidence of whole atoms using scanning tunnelling microscopes. In Figure 2.20 we are again observing only indirect evidence of the existence of two very strange particles. The images show the tracks produced in devices called cloud chambers or bubble chambers. The chambers contain gas or liquid that is at the very edge of a change of state. The introduction of any impurity, such as a particle, results in a trail of some kind. In cloud chambers, the trail is made from condensed vapour, like the con-trails left behind by jet aircraft high in the atmosphere. In bubble chambers, the trails consist of vapour formed by the particles as they travel through a superheated liquid – often liquid hydrogen.

Scientists place the chambers inside electromagnetic fields. This means that any particle carrying an electric charge which passes through the chamber will be affected; for example, it will be attracted to and repelled by one or other side of the chamber. The direction of the trail and the rate at which the particle is deflected gives information about the momentum the particle has (see Chapter 7).



■ **Figure 2.21** Ionization or vapour trails produced in a cloud chamber

What holds matter together?

■ **Figure 2.22** ATLAS experiment at the Large Hadron Collider, Geneva

In Figure 2.20a, the particle trail can be seen as a curve passing vertically across the chamber just to the left of centre. In 1932 US physicist Carl D. Anderson (1905–91) deduced from the trail that it had all the properties produced by a **beta particle**, which is an electron moving very fast through space, except for one: it had a *positive* electrical charge. In 1928 British physicist Paul Dirac (1902–84) had hypothesized using Einstein's theory of relativity that all particles of matter might have associated **antimatter** particles, with the same mass but the opposite electrical charge. Anderson had shown that this strange idea was a reality and in 1936 he was awarded the Nobel Prize for his discovery of an antimatter particle, the **positron**.

The complicated tangle of trails in Figure 2.20b is produced when a particle called a **meson decays** (changes) into other particles. Mesons were known at this point to have many of the properties of nucleons such as protons and neutrons, but the particles they changed *into* suggested that they themselves consisted of smaller particles of matter and antimatter joined together.

By the middle of the twentieth century, scientists felt that experimental evidence meant they were confronted with a 'zoo' of particles, all with different properties of charge and mass, and now even a whole new type of exotic antimatter. In this situation, scientists try to determine underlying patterns that suggest relationships between the particles.

If we are to make sense of this, we need to do a little fundamental physics ourselves. You may wish to refer to Chapter 4 of *MYP Sciences by Concept 3* to refresh your memories.

ACTIVITY: Feel the force – gravitation

■ ATL

■ Critical-thinking skills: Interpret data; Draw reasonable conclusions and generalizations

■ **Figure 2.23** A force meter or 'Newton' meter (sometimes called a spring balance) uses a spring adjusted to stretch a known amount for a given gravitational force

Method

You will need:

- **masses of known quantity (for example 10 g, 50 g, 100 g)**
- **a force meter.**

Use the newton meter to find the gravitational force produced by different masses. In your experiment plan, clearly identify the variables that are:

- **controlled (changed, and kept the same)**
- **measured.**

Record your results clearly in a table, showing the units of measurement in the heading.

Analysis

Show your results on a graph with the *independent variable* on the x-axis and the *dependent variable* on the y-axis. (Unsure which variable is which? See Chapter 1.)

The points on your graph should appear to be in a straight line, although the line might 'wiggle' somewhat due to *scatter* in the points. What might have caused the scatter in the measurements?

Since the points appear to be so close to a straight line, we can probably make the assumption that the relationship between mass and force is *linear* – that is, *each mass gives the same increase in force.* We can then **draw** a 'best-fit' line through as many of the points as possible, or as close to them as possible.

Conclusion

State the relationship between mass and gravitational force.

Evaluation

Evaluate your results. How sure are you that your experimental data gave a reliable result (clue: what about that 'wiggle' and 'scatter')? How could you improve the reliability of the data?

◆ Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion C: Processing and evaluating.

THINK–PAIR–SHARE

Think about everything you know about the fundamental forces of gravitation, electricity and magnetism. Note the ideas down on a piece of paper as they occur to you.

In **pairs**, compare your ideas. **Share** with the class anything new you learnt from your partner.

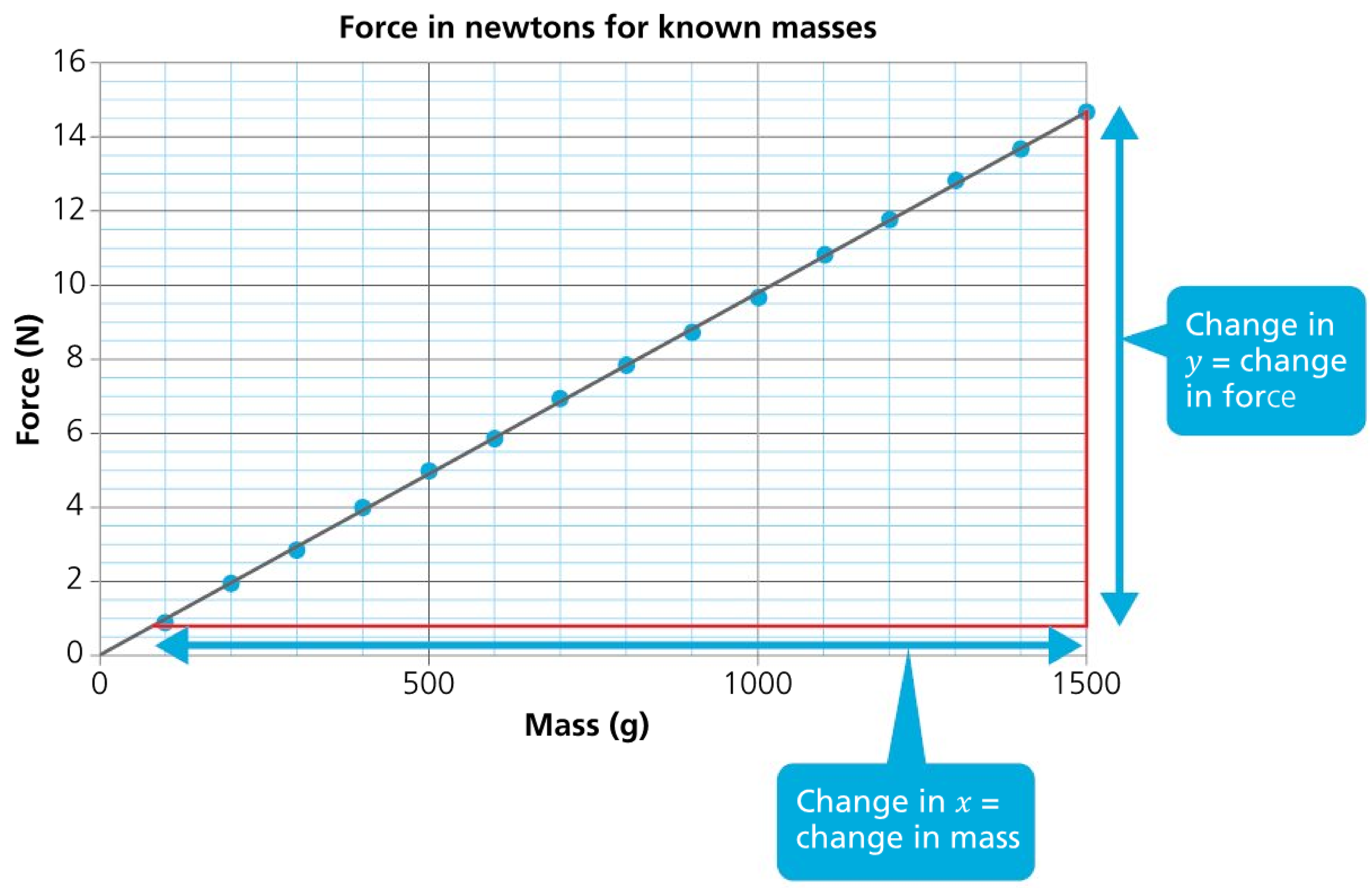
Finding the rate of change

Finding the slope or gradient of a straight line is a key skill in mathematics and enables us to deduce the equation of the line.

Using this straight line, we can now figure out the *relationship* between the mass and the force – that is, how much the force increases for each additional mass. We can do this by finding the gradient or slope of the line on the graph:

$$\text{gradient} = \frac{\Delta y}{\Delta x} = \frac{\text{change in } y}{\text{change in } x} = \frac{\text{change in force}}{\text{change in mass}}$$

One way to do this is to **draw** a right-angled triangle on the graph, as large as possible so that it encompasses the greatest possible range of results:



■ **Figure 2.24** Force in newtons for known masses

Use your graph to **calculate** the gradient of your line.

ACTIVITY: Feel the force – magnetism

ATL

- Critical-thinking skills: Interpret data; Draw reasonable conclusions and generalizations

In this experiment you will **measure** the variation of force with distance between two magnets.

Small neodymium magnets are very strong. They are usually disc shaped. One side of the disc is the 'north' pole of the magnet and the other is the 'south' pole.

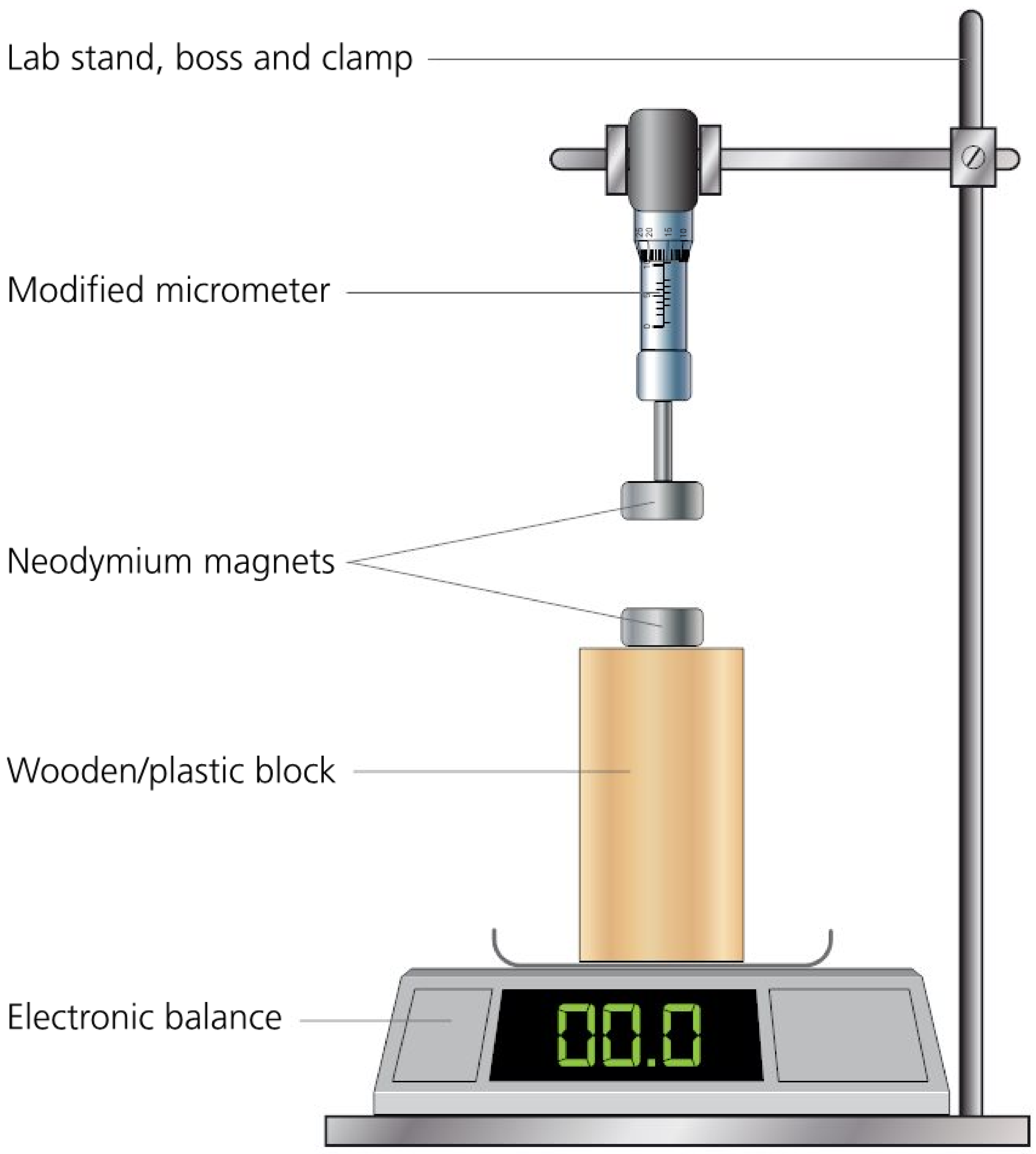


Figure 2.25 Experiment set-up to measure magnetic force

Equipment

You will need:

- **lab stand, boss and clamp**
- **a sensitive electronic top-pan balance**
- **two small neodymium magnets**
- **a block of non-magnetic material (wood, plastic or similar)**
- **some sticky tack, double-sided sticky tape or similar**
- **a modified Vernier micrometer or a similar screw assembly.**

Method

1. **The Vernier micrometer allows you to change the distance between the 'bits' with great accuracy. If possible, for this experiment your teacher or lab technician can remove the 'C'-shaped part to leave just one of the bits. If not possible, you can use any other kind of screw mechanism to position the magnet accurately.**
2. **Set up the apparatus as shown. Stick one of the magnets to the top of the block and the other to the bottom of the micrometer or screw.**
3. **BEFORE placing the micrometer in position in the clamp, press the 'TARE' or 'ZERO' button on the balance. This resets the balance reading to zero, compensating for the weight of the block and magnet.**
4. **Adjust the distance between the magnets using the boss and clamp until you *just* see a change in reading on the top-pan balance. If the reading increases, then the magnets are oriented to repel. If the reading decreases, the magnets are attracting each other.**
5. **Now use the apparatus to make measurements of the variation of the force between the magnets with distance.**
   - **What *range* of readings will you make?**
   - **What *interval* between readings will you use?**

   (See *Reading a Vernier scale* on page 39.)
6. **After taking one set of readings, flip one of the magnets around so that they are now interacting in the opposite way to before. Repeat your experiment, taking new readings.**

Results

Organize your readings in a suitable table, clearly showing the units of measurement.

Present your readings using a graph as before. Careful! Think carefully about your independent and dependent variables.

Interpret your results. **Identify** the pattern in the results. (See *Finding the fit* on page 42 to discover how to use a spreadsheet program to help with this.)

Conclusion

Summarize your results using this starter sentence:

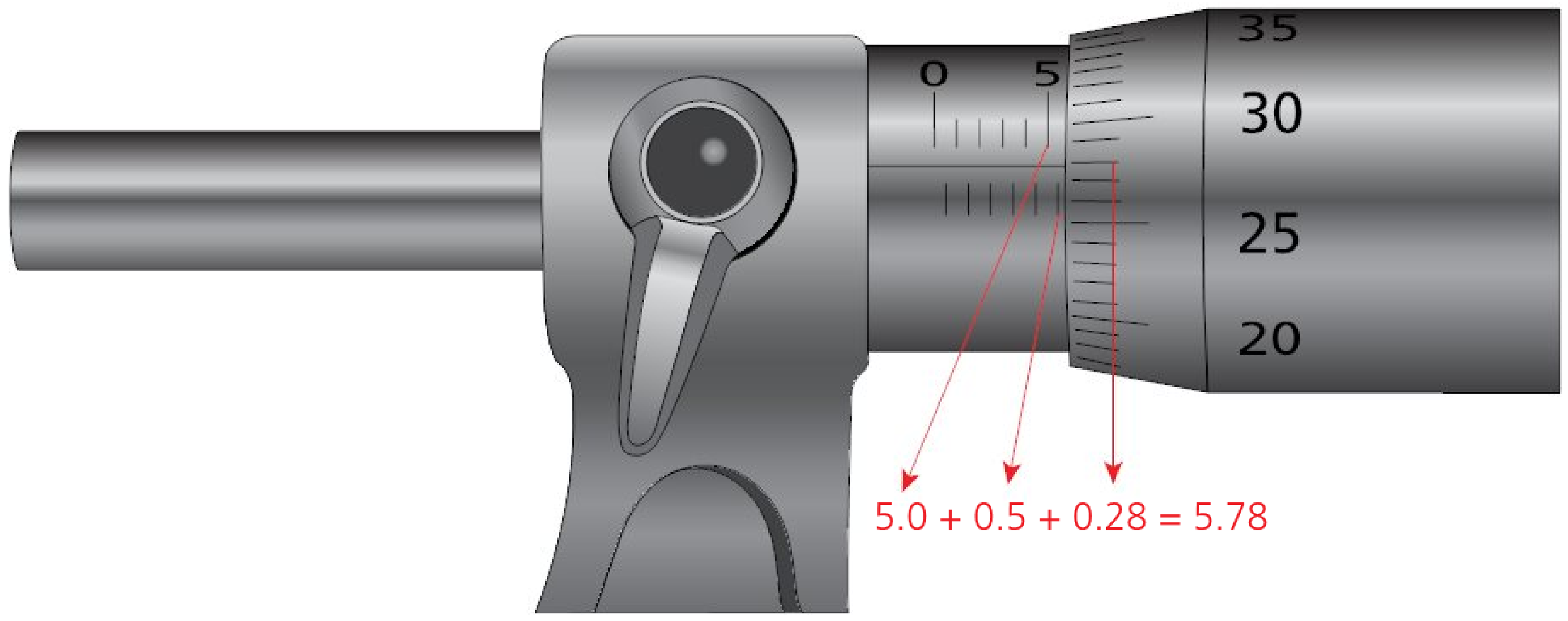
The force between two magnetic poles varies with distance in this way:

◆ Assessment opportunities

- ◆ In this activity you have practised skills that are assessed using Criterion C: Processing and evaluating.

Reading a Vernier scale

A Vernier scale is a common method for reading quite precise measurements of distance. On the micrometer you will see two different scales.



■ **Figure 2.26** Vernier micrometer scale

The first (main) scale is on the barrel of the micrometer and measures in millimetres above the line, with gradations for 0.5 mm below the line. The second scale is on the rotating 'thimble' part and measures to an accuracy of 0.01 mm.

In the example shown in Figure 2.26, you would obtain the reading like this.

- Read the measurement on the barrel first. The edge of the thimble indicates the first part of the measurement on this scale. We can see the 5 mm mark, and we can also just see the next half-millimetre mark below the line. So the first part of the reading is 5.0 + 0.5 = 5.5 mm.
- Read the measurement on the barrel by looking for the gradation which is nearest to the centre line on the barrel. In this case the centre line of the barrel is closest to the line representing 0.28 mm.
- Add these measurements together for the total reading: 5.5 + 0.28 = 5.78 mm.

The newton gravitational force is properly known as the **weight** of an object.

weight = mass × gravitational field strength

$$W = mg$$

where g = 9.81 newtons per kilogram (N kg^{-1}) on Earth

Notice that the gravitational field strength, g, for the Earth is actually a little less than 10 newtons for every kilogram of mass.

Of course, we are used to thinking of our 'weight' in kilograms, however this is a little misleading. To a physicist, kilograms are a measure of **mass**, the amount of material in your body, and not of the gravitational force produced on it.

The different fundamental forces we experience do seem to behave in similar ways. We know that electrical and magnetic fields are very similar because magnetic fields are produced by the arrangement of electrons in certain kinds of atom, so scientists combine these into one force called **electromagnetic force**. Meanwhile, gravitation seems to share some properties of the other two (it is produced by the interaction between masses and its size depends on the multiplication of the masses) and it has the same $\frac{1}{r^2}$ relationship with distance as the force field fills the space around the mass. Yet gravitation does not – as far as we know – ever repel. Notice too the difference in the values of the constants in the equations. Electromagnetic forces tend to be *much* stronger over short ranges and gravitational forces are relatively weak; after all, it requires a mass the size of a planet to keep us down!

These intriguing similarities have led scientists to suspect there may be some other, underlying, mechanism which brings them all together; a 'unified' theory of force.

However, as we reduce our scale of measurement to the level of the nucleus, something goes wrong. Perhaps you noticed this problem already?

ACTIVITY: Comparing forces

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument

1 Copy and complete the table to summarize the properties of the forces you have explored. The column for electrical forces has been completed for you.

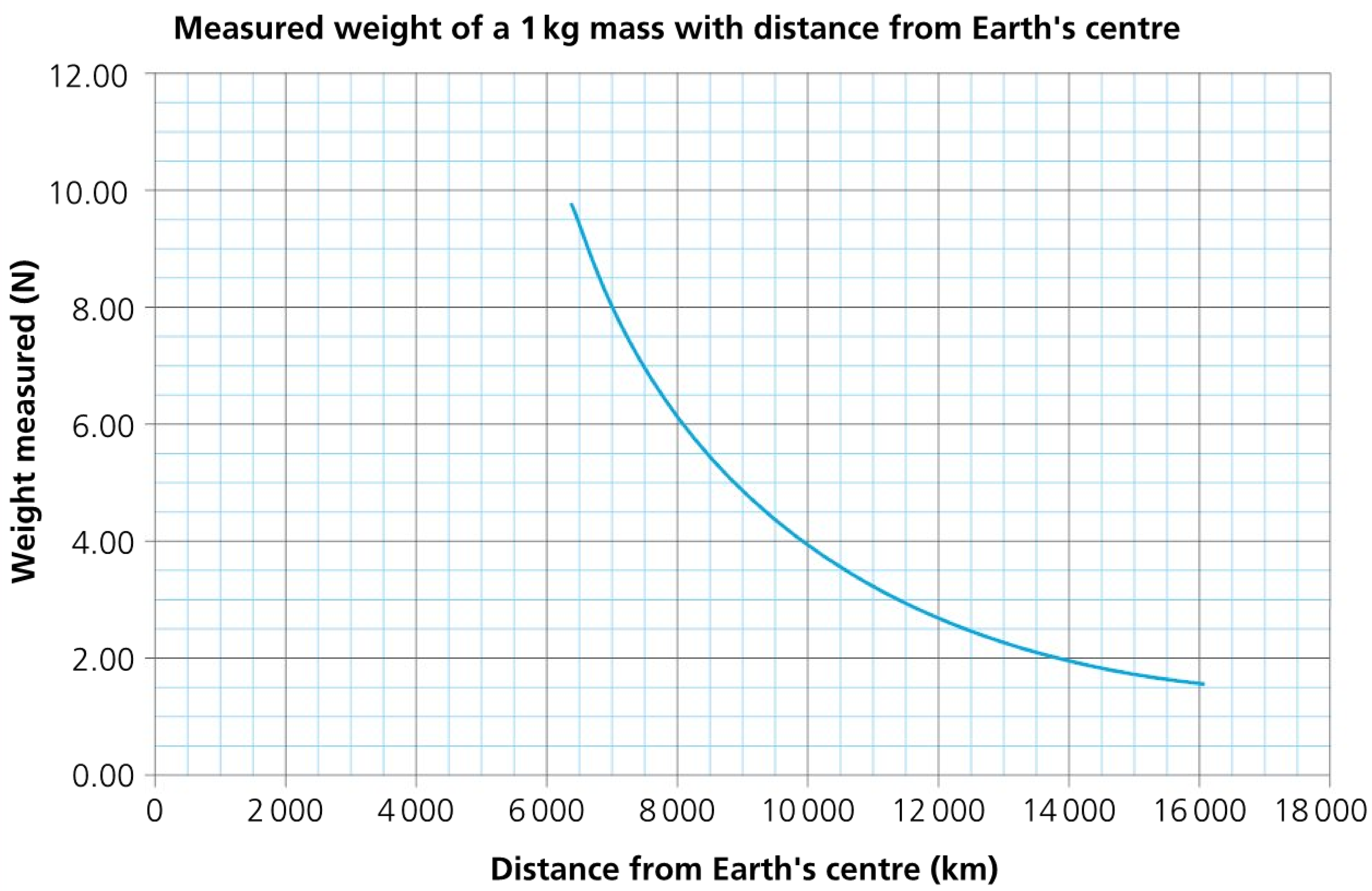
Properties	Electrical force	Magnetic force	Gravitational force
origin (caused by …)	electric charge		
SI unit of strength for origin	coulombs (C)		
values	positive (+) and negative (–)		
attracts?	yes		
repels?	yes		

■ **Table 2.4** Properties of force fields

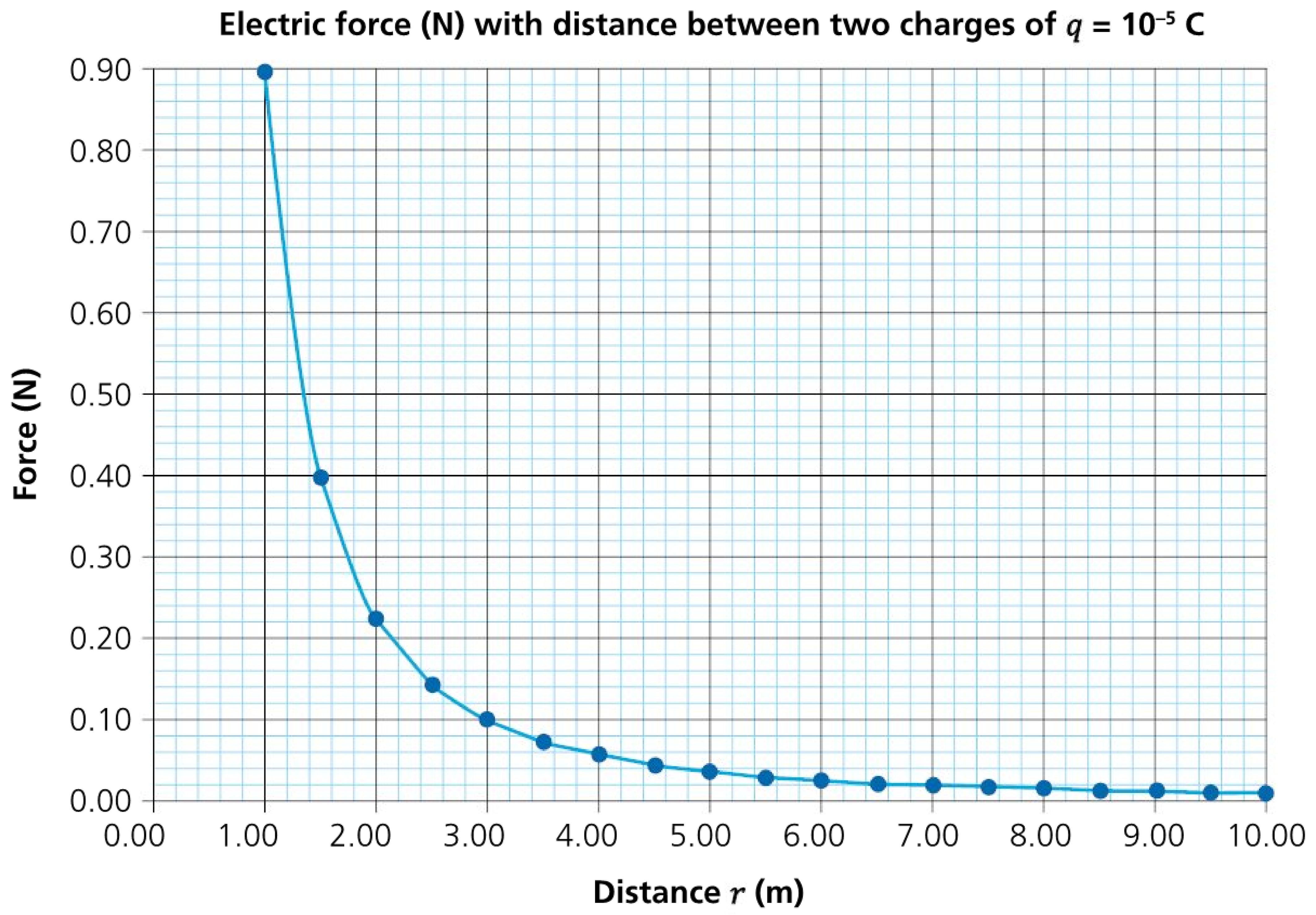
2 Interpret the information to compare and so evaluate the differences between the forces. Present your ideas using a visual Venn organizer with three interlocking circles.

In the circles, write the properties of the different forces from the table. If the forces share any properties, write those in the overlapping sections of the Venn circles.

Figures 2.27 and 2.28 show graphs for the variation of gravitational and electrical forces with distance.



■ **Figure 2.27** Weight of a 1 kg mass with distance from the Earth's centre



■ **Figure 2.28** Force between two charges with distance

3 Compare these graphs with your results from the activity: *Feel the force – magnetism.* What do you notice about the way that all the forces vary with distance? Summarize your conclusions.

The equations that describe the variation of gravitational and electrical forces are given below.

Newton's law of universal gravitation

$$F = G\frac{m_1 m_2}{r^2}$$

where F is the force between two masses, m_1 and m_2, separated by a distance r, and G is the *gravitational constant* = $6.67 \times 10^{-11}\,\mathrm{m^3\,kg^{-1}\,s^{-2}}$

Coulomb law of electrical force

$$F = k\frac{q_1 q_2}{r^2}$$

where F is the force between two charges, q_1 and q_2, separated by a distance r, and k is the *coulomb constant* = $8.99 \times 10^{9}\,\mathrm{N\,m^2\,C^{-2}}$ (in air)

4 Compare the equations to each other and to the graphs. What do you notice?

5 Summarize your ideas about the forces produced by electrical, gravitational and magnetic fields.

◆ Assessment opportunities

- In this activity, you have practised skills that are assessed using Criterion A: Knowing and understanding.

The protons in the nucleus hold a positive electrical charge, while the neutrons have no charge. The protons should be repelling each other and, since they are very close together indeed, this repulsion should be huge. Scientists could not explain why the nucleus of any atom bigger than hydrogen does not fly apart into its constituent nucleons. The only hypothesis they could propose was that there was *another* force acting *inside* the nucleus which was very strong, yet with very short range. Imaginatively, they named this the 'strong force'. Furthermore, investigation into the process of radioactive decay suggested that another force, less strong than the first, was acting; scientists called this the 'weak force'. Table 2.5 overleaf summarizes the known properties of all these fundamental forces.

Finding the fit

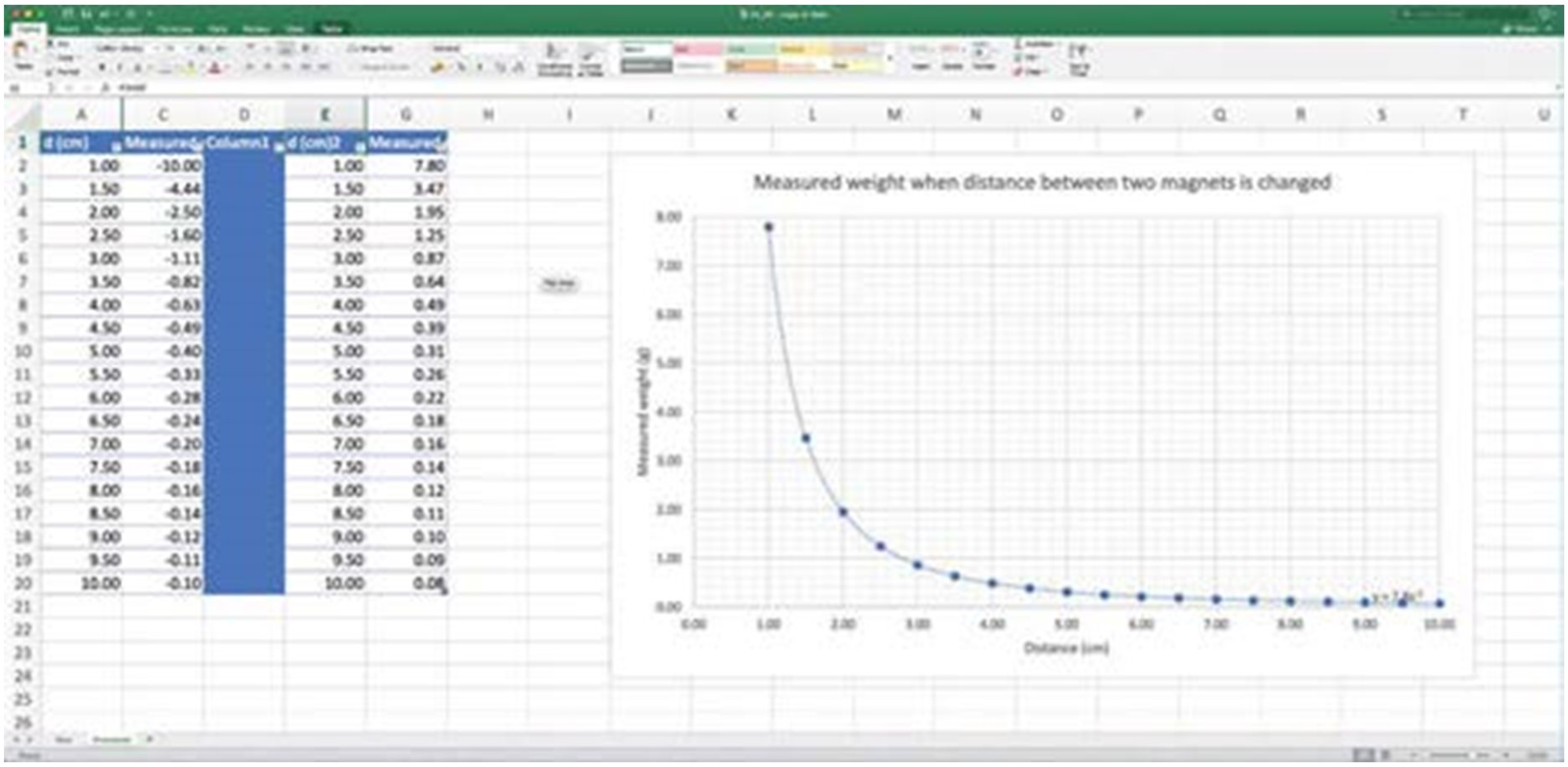
You can use a spreadsheet to plot the graph for your data (see Chapter 1 of *MYP Sciences by Concept 2* to refresh your memory). One way to find out the relationship between your variables is to use the 'trendline' function on the spreadsheet. The instructions opposite show how to do this in Microsoft Excel, but all spreadsheets will have a similar function. Alternatively, use the graph-plotting software recommended by your mathematics department!

Step 1: Once you have plotted the scatter graph, click on any of its points so that the whole curve is highlighted.

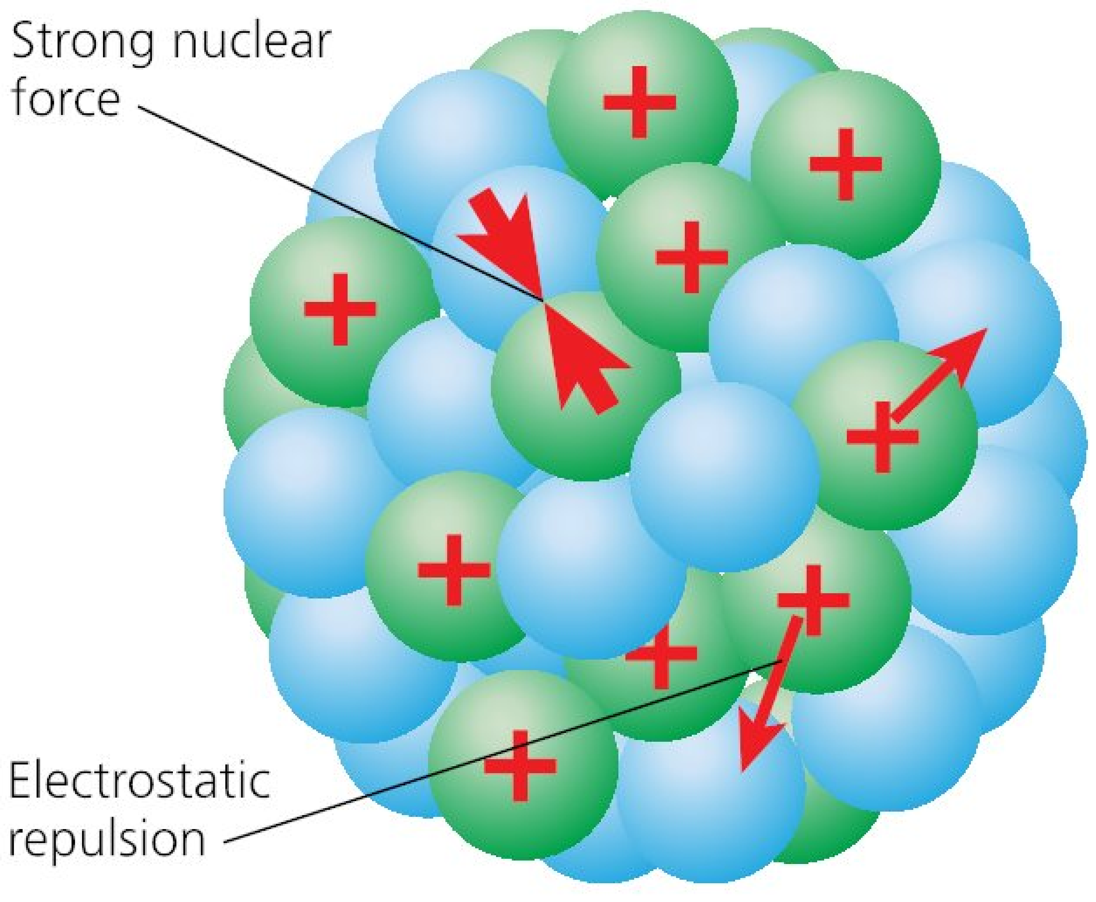
Step 2: Right-click on any of the dots. A menu appears. Select 'Add trendline'.

Step 3: In the right-hand panel, select the different trendline types until you find one that seems to fit the data well.

Step 4: To view the equation that describes this trendline, select 'Display equation on chart'.



■ **Figure 2.29** Screenshot of the spreadsheet in Microsoft Excel



■ **Figure 2.30** Forces inside the nucleus

Force	Relative strength (compared to strong nuclear = 1)	Distance of action/m
strong nuclear	1	$<10^{-15}$ = less than size of a nucleus
electromagnetic	$1/137 = 7.2 \times 10^{-3}$	infinite
weak	approximately 10^{-6}	10^{-18} = approximate size of a proton
gravity	6×10^{-39}	infinite

■ **Table 2.5**

What building blocks do scientists use to describe non-living matter?

CLASSIFYING THE PARTICLE ZOO

In 1961 US physicist Murray Gell-Mann (1929–) derived a classification system that used symmetry to suggest that nucleons and mesons might, in fact, all share another property. He suggested that the underlying component was even tinier particles, which he called 'quarks'. Gell-Mann's hypothesis was based on mathematical modelling, but in 1968 scientists at the Linear Accelerator at Stanford University, USA, bombarded nucleons with very high-energy electrons and the particle traces produced suggested that protons and neutrons did indeed have 'structure' *inside* them. This was taken as evidence of Gell-Mann's quarks.

Quarks are incredibly weird. While we may conceptualize them as tiny particles, they possess extraordinarily high energies and are held or 'contained' inside the tiny space of a single nucleon. They do not really behave like particles of matter as we might imagine them. Similar experiments at the HERA collider in Hamburg, Germany, by a team from Cornell University estimated that quark radii must be no larger than 0.43×10^{-18} m. At first it seemed that there were *two* kinds of quark, which were called 'up' and 'down', with electric charges of $+\frac{2}{3}e$ and $-\frac{1}{3}e$, respectively. This meant that to form protons and neutrons they had to combine in threes.

Nucleon	Charge/multiples of electron charge $e = 1.6 \times 10^{-19}$ C	Quark structure *u* = up, *d* = down
proton, *p*	$+1e$	*uud*
neutron, *n*	0	*udd*

Table 2.6 Quark structure of nucleons

What was keeping the quarks in? Scientists realized that the strong force was responsible for holding the quarks together, but that this force field must be very different in properties from the other fundamental forces because it was confined to the scale of nuclei. It does not diminish with distance but rather *increases* with distance, similarly to the way an elastic band exerts a greater force the more it is stretched. Just as electromagnetic interactions are caused by a property we call 'charge', strong force interactions are given the attribute of 'colour'; nothing to do with the colours we observe, this is just a label for the property.

Links to: Language and literature

Poetry, literature, faith and the scientific imagination

Gell-Mann named his symmetrical particle scheme 'the eightfold way' in analogy with the importance of the number eight in the Buddhist faith. Similarly, he chose the name 'quarks' in reference to a scene in *Finnegans Wake* by James Joyce, when a barman makes a slip of the tongue and calls out 'Three quarks for Muster Mark!' instead of three *quarts*. In fact, both these discoveries were made almost simultaneously by others; the eightfold way by Yuval Ne'eman in Israel and the particle postulate by US physicist George Zweig. Zweig called his particles 'aces', but somehow Gell-Mann's quarks caught on! What role do other kinds of knowledge have as inspiration for new scientific ideas?

What other particles contain quarks? It turns out that mesons – the particles detected in the 1950s – exhibit similar structure to nucleons, but this time they only seemed to contain *two* quarks. Yet mesons are not detected with charge that has fractions of *e*. How can this be when we know that up and down quarks have charges that are multiple of $\frac{1}{3}e$? This, in turn, led scientists to postulate the existence of *antiquarks*, which are antimatter quarks with the same properties as their matter cousins but with the *opposite* charge.

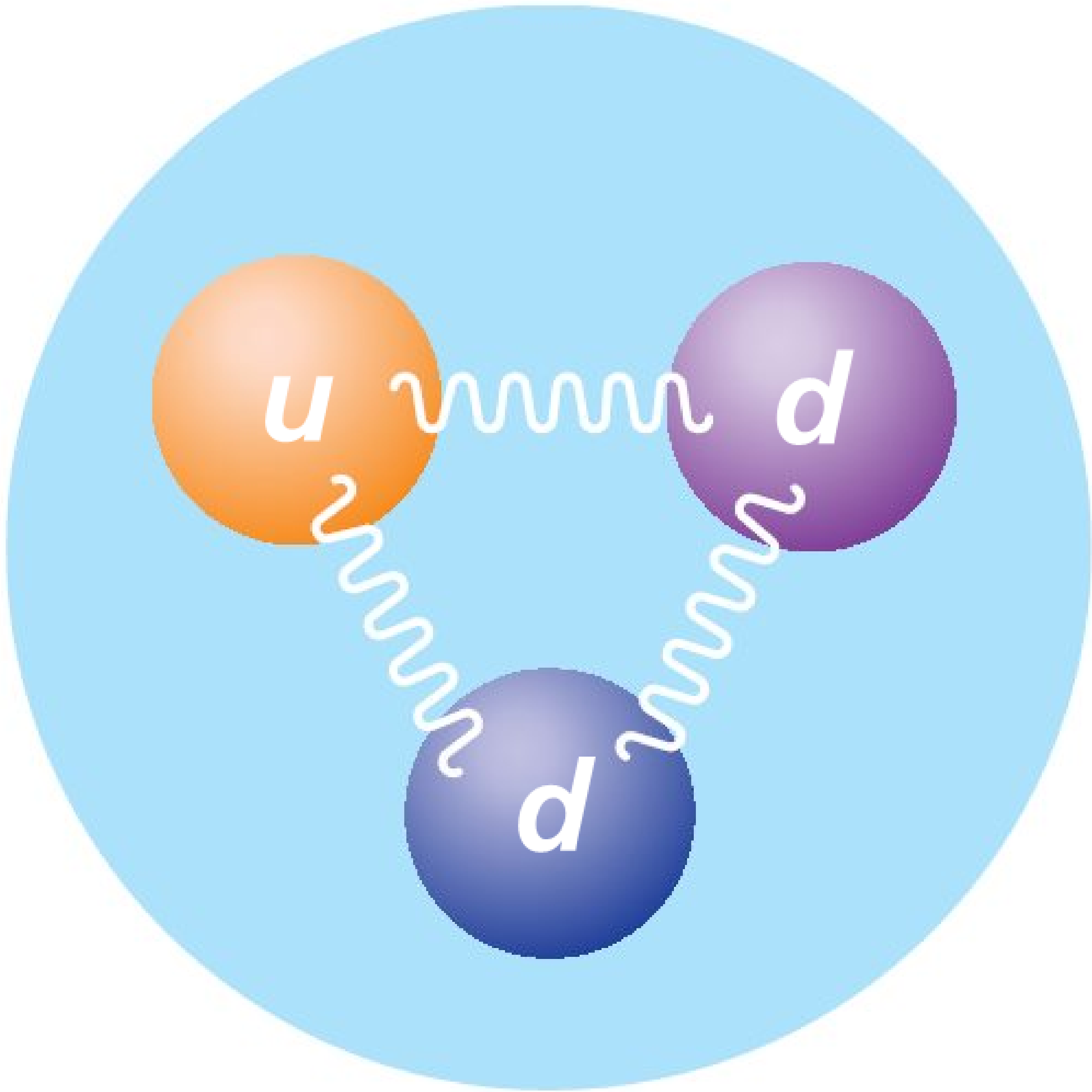


Figure 2.31 Nucleons are formed from quarks bound together by the strong force, which behaves like an elastic band!

Example mesons (there are many more …)	Charge	Quark structure u = up, d = down $\bar{u}$ = anti-up, $\bar{d}$ = anti-down
+ pion π^+	$+1e$	$u\,\bar{d}$
– pion π^-	$-1e$	$d\,\bar{u}$

■ **Table 2.7** Quark–antiquark structure of some mesons

What about electrons? Would they turn out to be made from something even smaller, such as quarks or antiquarks? In fact, not as far as we know; electrons appear to be fundamental and indivisible. They belong to a class of particles known as the **leptons** which also includes some other particles called muons and neutrinos.

Quarks enabled scientists to establish a pattern to all the members of the 'particle zoo' which became known as the **Standard Model**.

ACTIVITY: Principal, I shrunk the science class! (the sequel)

ATL

- Creative-thinking skills: Consider multiple alternatives, including those that might be unlikely or impossible; Create original works and ideas; Use existing works and ideas in new ways
- Communication skills: Use appropriate forms of writing for different purposes and audiences
- Information literacy skills: Access information to be informed and inform others

Now that you have explored the Universe at different scales, return to the draft report you wrote at the beginning of this chapter.

Review your observations, and use this thinking routine to evaluate it:

I used to think …

Now I think …

What I would like to know now is …

Now finish your report, incorporating the new discoveries you have made.

<table>
<tr><th colspan="16">FERMIONS
(spin $s = \frac{1}{2}, \frac{3}{2}, \frac{5}{2}$)</th></tr>
<tr><td colspan="8">HADRONS
Consist of quarks and antiquarks</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="4">BARYONS
3 quarks</td><td colspan="4">MESONS
2 quarks</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">p</td><td colspan="2">n</td><td>π^+</td><td>π^+</td><td>K^+</td><td>many more …</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="8">QUARKS and antiquarks
Exist in three 'generations' according to energy state</td><td colspan="8">LEPTONS and antileptons
Fundamental particles</td></tr>
<tr><td colspan="2">u</td><td colspan="2">d</td><td colspan="2">$\bar{u}$</td><td colspan="2">$\bar{d}$</td><td colspan="2">e</td><td colspan="2">ν_e</td><td colspan="2">$\overline{e^+}$</td><td colspan="2">$\bar{\nu}_e$</td></tr>
<tr><td colspan="2">c</td><td colspan="2">s</td><td colspan="2">$\bar{c}$</td><td colspan="2">$\bar{s}$</td><td colspan="2">μ^-</td><td colspan="2">ν_μ</td><td colspan="2">$\overline{\mu^+}$</td><td colspan="2">$\bar{\nu}_\mu$</td></tr>
<tr><td colspan="2">t</td><td colspan="2">b</td><td colspan="2">$\bar{t}$</td><td colspan="2">$\bar{b}$</td><td colspan="2">τ^-</td><td colspan="2">ν_τ</td><td colspan="2">$\overline{\tau^+}$</td><td colspan="2">$\bar{\nu}_\tau$</td></tr>
</table>

BOSONS (spin s = 0, 1, 2, 3 …)				
Strong force	Weak force	Electromagnetic force	*Gravity?*	Mass particle
Gluons g	W^+ W^- Z^0	Photon γ	Graviton* G?	Higgs Boson H

* note that the graviton is a hypothetical boson for gravitational force and has not been detected

■ **Table 2.8** The Standard Model organizes the particle zoo into categories. The different categories of particle interact using different fundamental forces and are broadly classified according to a property named 'spin'. The fundamental forces are in turn transmitted by different 'force exchange' particles called *gauge bosons*.

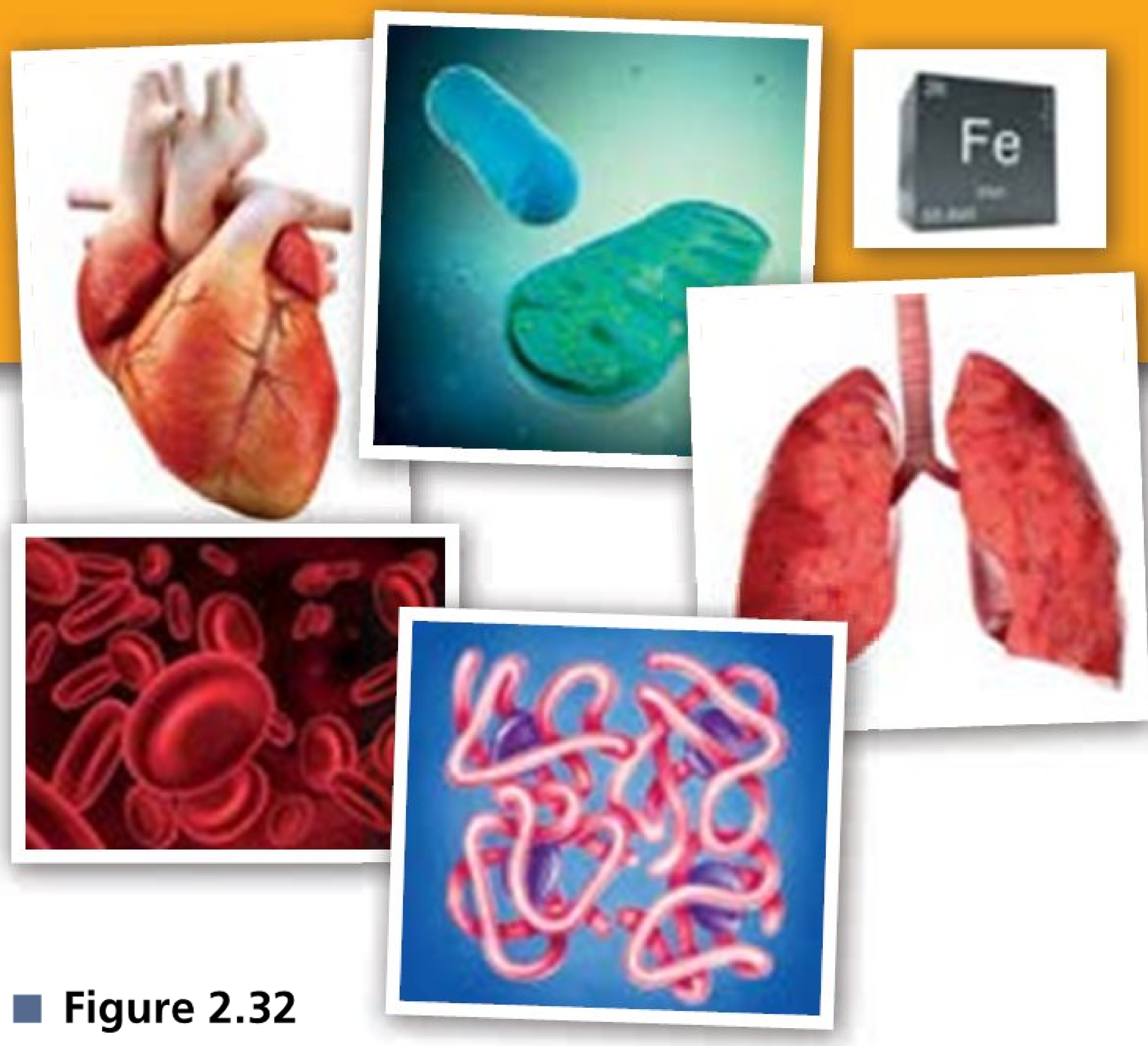


Figure 2.32

SOME REVIEW PROBLEMS TO TRY

1 **Organize** the structures in Figure 2.32 on a size scale from the smallest size to the largest size (the images are not drawn to scale). Use scientific knowledge to support your answer.

2 **Describe** the relationship between the different levels of the structural organization in humans: cells, tissues, organs, organ systems, organism.

3 a **Deduce** the electron arrangements of the following elements:
   - i helium
   - ii oxygen
   - iii potassium.

   b **Draw** the electron shell diagram for each of the elements in part (a).

   c Figure 2.33 shows the electron shell diagram a student drew of a fluorine atom. **Describe** why the diagram is incorrect.

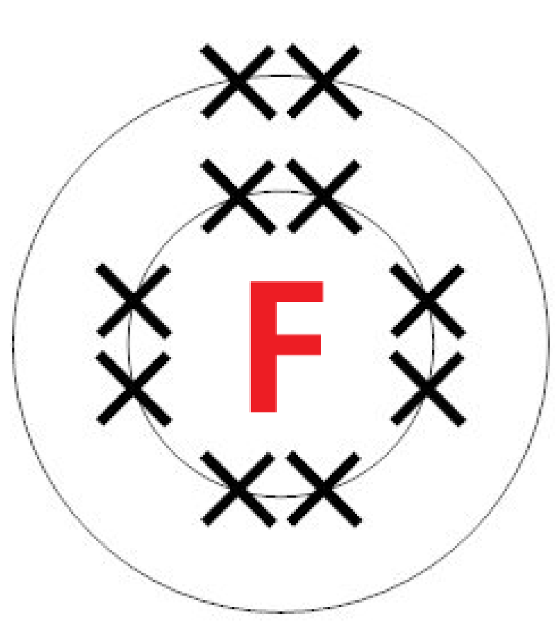


Figure 2.33

   d Wherever you look, you will find very similar models of the atom. **Analyse** and **evaluate** how accurate this model is compared to the true structure of an atom, and how useful it is as a model.

Reflection

In this chapter we have looked at the scale of things and **organized** different structures from their biggest components to the smallest. We **compared** the scale of living and non-living things and inquired about the smallest particles that build them up. We **outlined** the similarities between the structural organization of plants and animals. We **summarized** the hierarchy of this structural organization and **discussed** the role of each structure to ensure the sustainability of organisms. We have **described** the structure of the atom, **defining** key terms such as atomic number and mass number, and **described** the sub-atomic particles in an atom and within nucleons. We **described** the arrangement of the electrons and **summarized** how forces act on matter of different types. We have used models and simulations to better understand the atom and **outlined** the work of key scientists in unfolding the mystery of the structure of the atom. Finally we have used analogies to **comment** on our understanding of the scales involved when dealing with individual atoms.

Use this table to reflect on your own learning in this chapter					
Questions we asked	Answers we found	Any further questions now?			
Factual					
Conceptual					
Debatable					
Approaches to learning you used in this chapter	Description – what new skills did you learn?	How well did you master the skills?			
		Novice	Learner	Practitioner	Expert
Learner profile attribute(s)	Reflect on the importance of being open-minded for your learning in this chapter				
Open-minded					

3 How do we organize the natural world?

We **develop our understanding** of the natural world by **discovering patterns** and **identifying relationships**, **organizing our knowledge in new ways**.

SEE–THINK–WONDER

Look at Figure 3.1. What do you **see**? What does it make you **think**? What does it make you **wonder**?

CONSIDER THESE QUESTIONS:

Factual: What is the periodic table? How are characteristics of living things used to classify them?

Conceptual: How do scientists use trends and patterns?

Debatable: To what extent does classification help or restrict our understanding of new information? How have technological advances affected our models of the world?

Now **share and compare** your thoughts and ideas with your partner or with the whole class.

IN THIS CHAPTER, WE WILL …

- **Find out** how patterns in form enable scientists to identify relationships in the natural world.
- **Explore** how those patterns and relationships have enabled scientists to organize living and non-living matter in different ways.
- **Take action** to explore how classification is important in the worlds of medicine and pharmaceuticals.

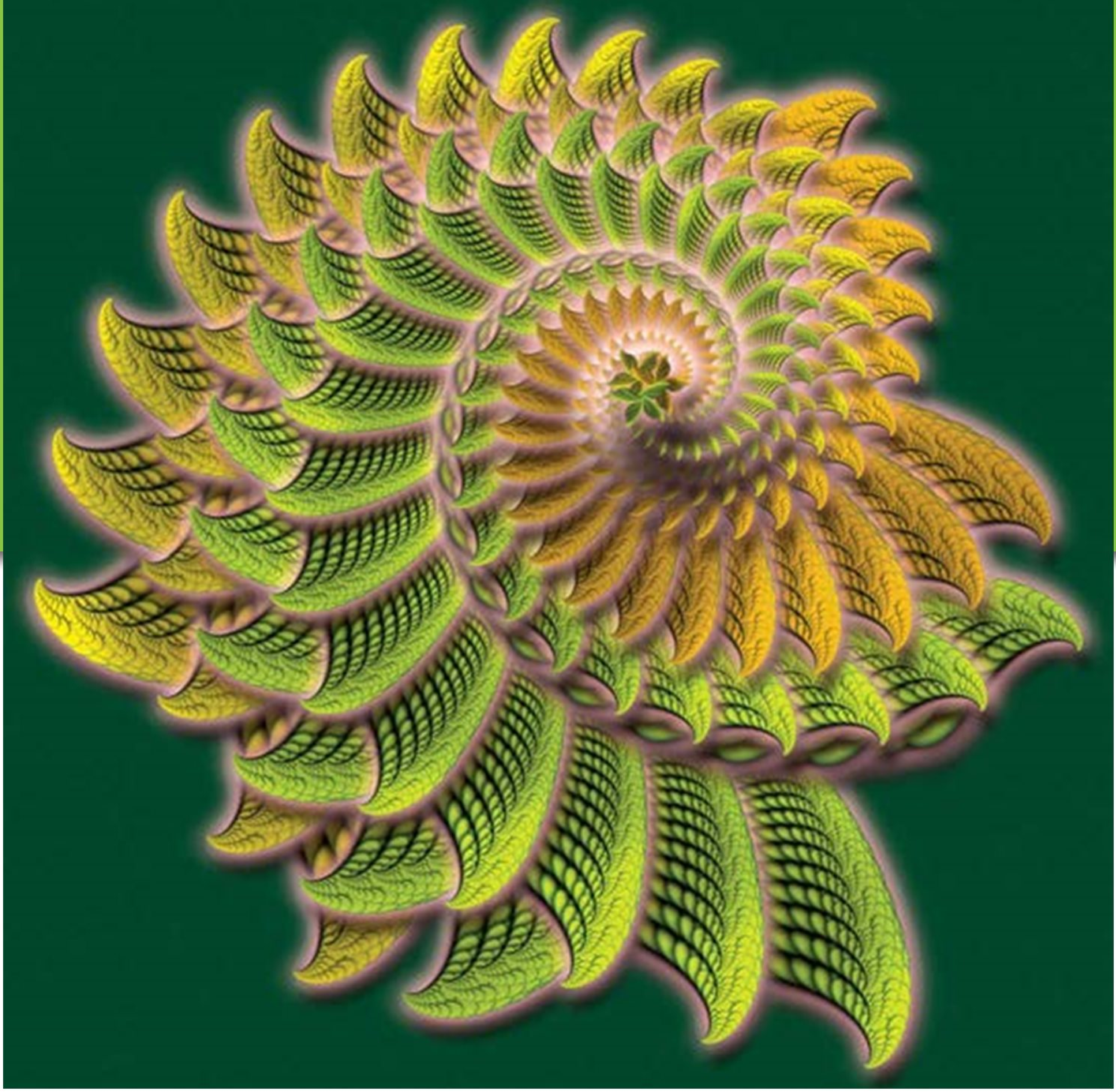
These Approaches to Learning (ATL) skills will be useful …

- Communication skills
- Collaboration skills
- Information literacy skills
- Critical-thinking skills
- Creative-thinking skills
- Transfer skills
- Media literacy skills

Assessment opportunities in this chapter:

The activities in this chapter will help you develop and evaluate your learning in these MYP Sciences learning objectives:

- **Criterion A:** Knowing and understanding
- **Criterion B:** Inquiring and designing
- **Criterion C:** Processing and evaluating
- **Criterion D:** Reflecting on the impacts of science



■ **Figure 3.1** Fractals show how patterns can help us understand complexity

KEY WORDS

category
classify
form
formula
formulae
function
property

We will reflect on this learner profile attribute …

- Thinkers – how have the patterns and relationships that scientists discovered in nature changed the way we think about the world?

Did the image make you think of natural forms, perhaps a seashell or a plant? In fact Figure 3.1 is a computer-generated image of a special kind of mathematical function called a **fractal**. The image looks very complex, but is produced by repeating the same mathematical operation over and over again. The fact that fractals produce very complex patterns from relatively simple but recurring functions reflects the way in which the complexity of the natural world can be understood more easily when we identify underlying patterns and relationships. In this chapter, we will explore two very important scientific patterns that have enabled us to understand the complexity of living and non-living matter.

What is the periodic table?

Symbol	English name	Origin of symbol
Ag	silver	Latin *argentums*
Au	gold	Latin *aurum*
Cu	copper	Latin *cuprum*, from 'Cyprus'
Fe	iron	Latin *ferrum*
Hg	mercury	Greek *hydrargyrum* meaning 'silver water'
K	potassium	Arabic *qalay*, which in Latin is *kalium*
Na	sodium	Latin *natrium*
Pb	lead	Latin *plumbum*
Sb	antimony	Latin *stibium*
Sn	tin	Latin *stannum*
W	tungsten	German *wolfram*

■ **Table 3.1** Elements with symbols that are not consistent with their English names

THE MODERN PERIODIC TABLE

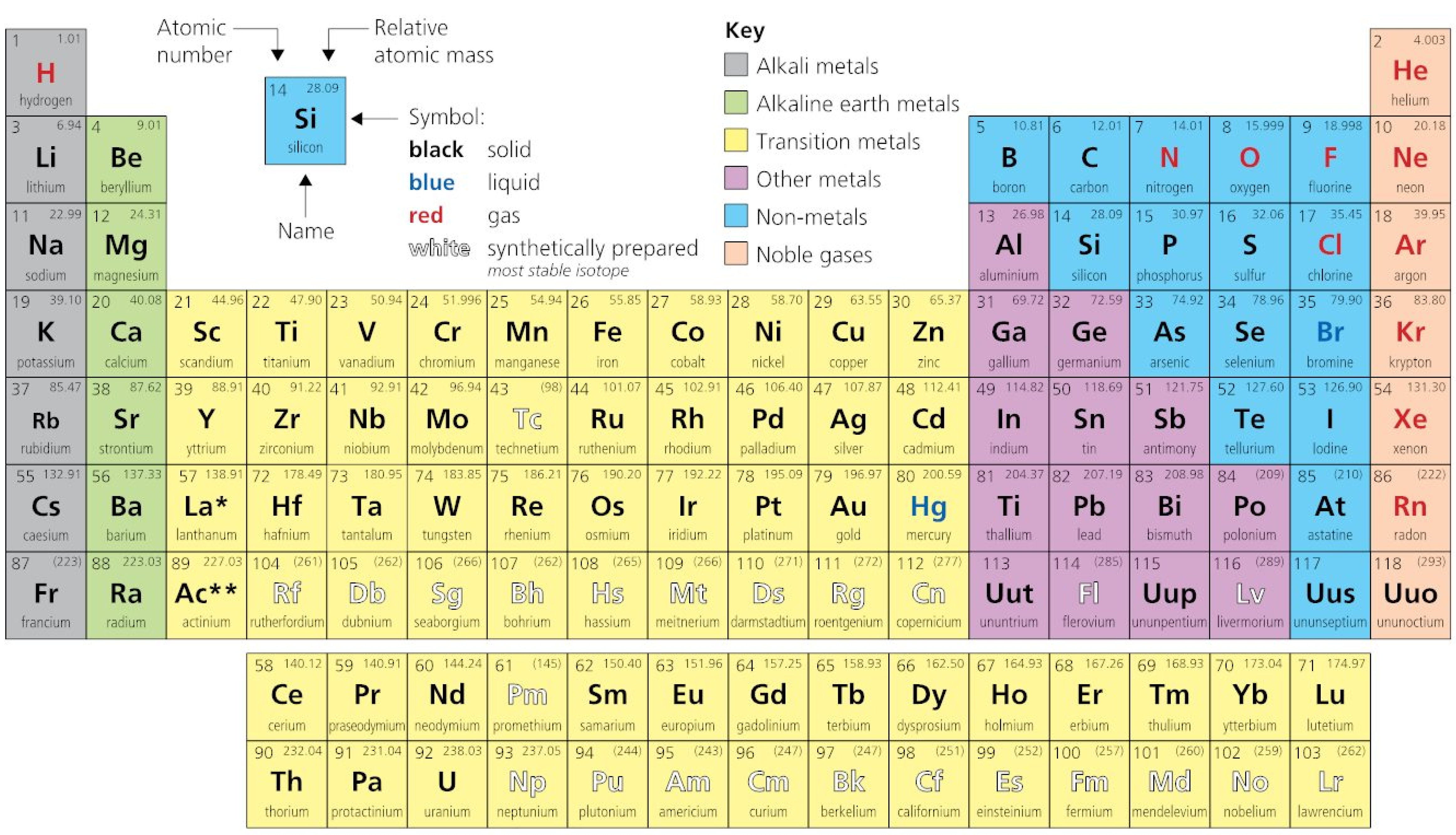
The modern periodic table is a tabular arrangement of the elements from which all matter is created, organized by increasing atomic number, Z. Each element is represented by a chemical symbol; rows of elements are called periods, while columns are called groups.

Using symbols

John Dalton was the first scientist to use symbols to represent the elements (Figure 3.3), although earlier mystical thinkers, now called **alchemists**, used a system of astrological symbols to describe the few substances they knew. Dalton understood that atoms could combine only in whole number ratios. By using symbols to represent the individual atoms in a substance, he could represent compounds as combinations of the symbols of the elements that comprised them, essentially coming up with what we now call 'chemical formulae'.

The main disadvantage of Dalton's symbols was that there was no logical order to them, which made them very hard to remember. In 1813–14, a new set of symbols was published by the Swedish scientist Jöns Jakob Berzelius. Inspired by Carl Linnaeus' classification system for living things, Berzelius gave each of the 47 elements known at the time a symbol based on the element's Latin name. He also went on to derive symbols for compounds. The system was hated by Dalton and initially rejected by the scientific community but was accepted by the mid-1800s and is still largely in use today.

An element's symbol may consist of one uppercase letter or two letters, uppercase for the first and lowercase for the second. While the symbols are based on the element's Latin name, it is not unusual for the symbol to also represent the English name as the English language has roots in Latin. There are, however, a few exceptions, as shown in Table 3.1.



■ **Figure 3.2** The modern periodic table (* and ** La and Ac are displayed in group 3 but belong to the lanthanoid and actinoid groups at the bottom of the table, respectively)

■ **Figure 3.3** Dalton's 36 symbols of the elements, as presented in *A New System of Chemical Philosophy*, 1805

Many element names find their origin in ancient myths including Greek and Roman gods, and a number of names have specific meanings when translated from the classical languages of Greek and Latin. This is because in the eighteenth and nineteenth centuries, science was considered more of a hobby, and therefore only practised by people from the upper classes of society who were educated in these languages.

ACTIVITY: Elemental games

ATL

- Communication: Use and interpret a range of discipline-specific terms and symbols; Use intercultural understanding to interpret communication
- Creative-thinking skills: Use brainstorming and visual diagrams to generate new ideas and inquiries; Make unexpected or unusual connections between objects and/or ideas

In this activity you will familiarize yourself with some of the elements in the periodic table and their symbols.

1 **Identify** elements that have been named after:
   a parts of the Solar System
   b countries or continents
   c places
   d scientists.
2 Use the following website to **identify** three elements whose names are from mythical beings: www2.ucdsb.on.ca/tiss/stretton/database/element_origins.html
3 Use the same website to find the meanings of the names bromine, dysprosium and technetium, and then find out a little about each element to **explain** why they were given these particular names.
4 In June 2016, the last four elements in the periodic table were assigned names. Research the origin of their names and **explain** how they conform to IUPAC guidelines for naming new elements, set out in the blue box below.
5 Challenge yourself to write a small sentence or phrase with element symbols, for example: tellurium, actinium, hydrogen, erbium, sulfur, potassium, nobelium, tungsten, nitrogen, oxygen, thorium, iodine, nitrogen = TeAcHErS KNoW NOThIN.

◆ Assessment opportunities

In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

▼ Links to: Language and literature

Language acquisition

The symbols of the elements were a new international scientific language. As you carry on through MYP Sciences, you too will become more and more familiar with this language. If you speak multiple languages you are likely to recognize the symbols of some of the elements and even be able to translate the meanings of some element names.

IUPAC guidelines

The guidelines for the naming of elements can be found at:

https://iupac.org/iupac-is-naming-the-four-new-elements-nihonium-moscovium-tennessine-and-oganesson/

Exploring the periodic table

You can explore the elements of the periodic table further using the many interactive periodic tables available online: search **royal society chemistry periodic table**, **TED periodic videos** and **interactive periodic table** to further explore its properties.

In Chapter 2 we discussed how elements are made up of identical atoms and that atoms themselves consist of protons, neutrons and electrons. The number of each sub-atomic particle present in the atom of any element can be determined simply by looking at the periodic table.

Select any element in the periodic table and have a look at the information provided for it more closely. You will notice its symbol, its name and two numbers, which are different except in the case of hydrogen where they are both 1. The smaller of the two numbers is always the atomic number, or proton number; this is also equal to the number of electrons present in an atom. The larger number represents the mass of the atom (protons + neutrons). You have learnt that to calculate the number of neutrons, you subtract the proton number from the mass number; but hang on a minute, most of the larger numbers in the periodic table are decimals! That means that we would have 'bits' of neutrons, which can't be possible.

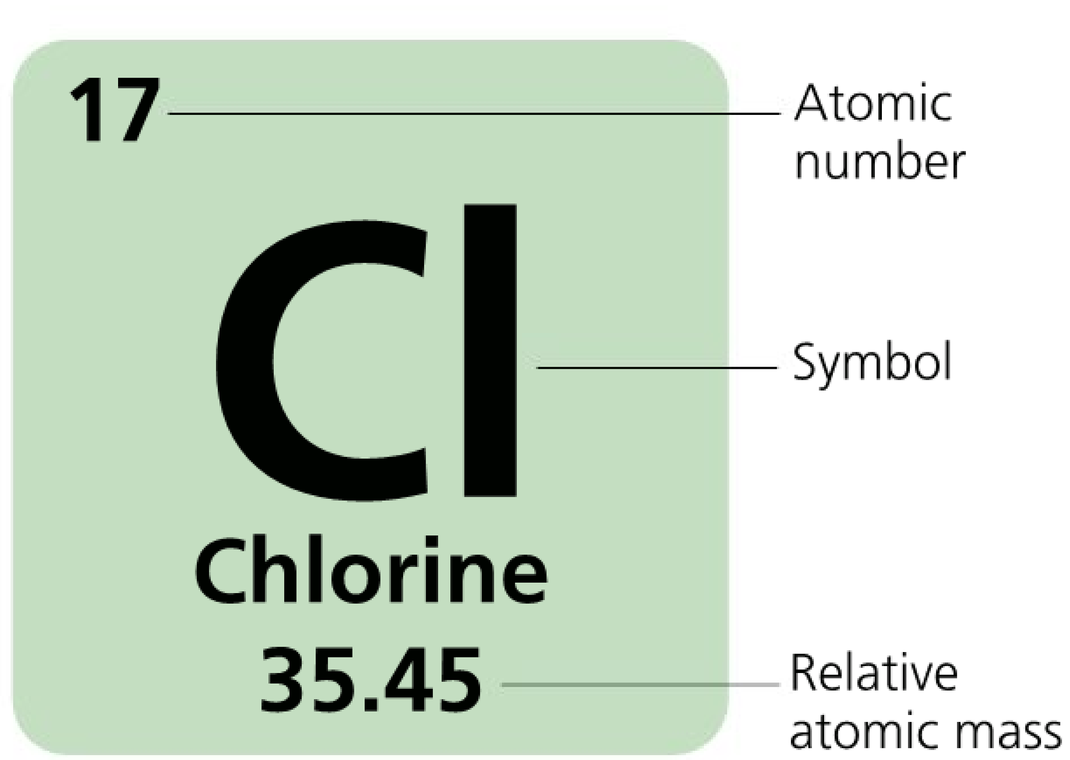


Figure 3.4 Chlorine, as shown in the periodic table

Atoms of a particular element can exist with different numbers of neutrons. Chlorine (element 17), for example, can exist with 17 protons, 17 electrons and 18 neutrons, giving it a mass number of 35, or with 17 protons, 17 electrons and 20 neutrons, giving it a mass number of 37. The atoms with a mass of 35 and 37 are **isotopes** of the element chlorine. Isotopes are atoms of the same element (so with the same proton number) with a different number of neutrons, hence different mass number. In order to account for the natural existence of a mixture of isotopes of an element, the larger number in the periodic table is the average mass of all of the isotopes of the element, taking their natural abundance into consideration. It is called the **relative atomic mass (RAM)**, shown by the symbol A_r.

The mass of each element is compared to a standard – the mass of one-twelfth of the mass of an atom of the carbon-12 isotope. So if helium has a mass of 4, its mass is $\frac{4}{12}$ of the mass of a carbon-12 isotope.

The first 92 elements in the periodic table are known as natural elements. This is because all of the elements up to and including uranium were created in stars in a process called **nucleosynthesis**. This process will be explored further in Chapter 10. The remaining elements, referred to as **transuranic** elements, are all extremely unstable as they decay radioactively and are usually synthesized in a laboratory.

EXTENSION

Find out more about how and why scientists came to choose carbon-12 as their reference atom for relative atomic mass.

HOW IS THE PERIODIC TABLE ORGANIZED?

Creating our modern periodic table

The periodic table you will most likely see displayed in your school laboratory is not the only periodic table that exists. No matter what the particular arrangement of elements chosen for a particular periodic table, they all have one thing in common. The clue is in the name …

In this section we will look at how we arrived at the structure we are familiar with today and why it is significant.

ACTIVITY: Re-enacting the development of the periodic table

ATL

- Transfer skills: Inquire in different contexts to gain a different perspective
- Communication skills: Use a variety of media to communicate with a range of audiences; Read critically and for comprehension; Paraphrase accurately and concisely
- Collaboration skills: Delegate and share responsibility for decision-making; Help others to succeed; Encourage others to contribute; Give and receive meaningful feedback

Your task today is to work in groups to **create** a 3-minute TV programme about the development of the periodic table that is suitable for an audience of students who are one year younger than yourselves.

The roles

Each member of the group will take on a role.
The roles are:

1. **Interviewer**
2. **John Dalton (1766–1844)**
3. **Johann Döbereiner (1780–1849)**
4. **John Newlands (1837–98)**
5. **Dmitri Mendeleev (1834–1907)**
6. **Paul-Émile Lecoq de Boisbaudran (1838–1912)**

How to begin

- Decide which role each group member will take on.
- Research the interviewees together to find out how their work contributed to the development of the periodic table. **Identify** key points that should come across in the interview and turn these into one or two questions that the interviewer can ask. **Create** flashcards with the answers that each scientist would provide to these questions.
- Work with the interviewer so that they understand what they need to ask each interviewee, making sure you **explain** the significance of the question with regards to the development of the structure of the periodic table.
- Think about how you can make your presentation resemble an actual TV programme as closely as possible and about how you can make it interesting to watch.
- After each presentation, give meaningful feedback to the group that presented, identifying two aspects of their presentation that you enjoyed and one that could be improved.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding and Criterion D: Reflecting on the impacts of science.

MEET A SCIENTIST: DMITRI MENDELEEV

Mendeleev is the most celebrated scientist when it comes to the periodic table. He excelled at the university of St Petersburg; he also worked in Paris and Heidelberg (the latter under Bunsen – of the Bunsen burner), where his work on the elements really took off and led to the development of the periodic table. But it is worth mentioning that in 1869 when Mendeleev published his periodic table, another chemist, Julius Lothar Meyer (who had also worked under Bunsen), published his own independently; in fact, the two scientists shared a prestigious prize called the Davy Medal in 1882.

There was no doubt how **knowledgeable** Mendeleev was when it came to the elements, which fuelled the self-confidence and self-belief needed to not only predict the existence of undiscovered elements, but even to predict their properties. On the other hand, his work did not lack mistakes and a huge amount of work took place between Mendeleev's 1869 periodic table and the one we have today. Later on in his life, Mendeleev's arrogance led to his refusal to believe in atoms, as well as other things that couldn't be seen like electrons and radioactivity.

Figure 3.5 A monument to Dmitri Mendeleev, with his 1869 periodic table on the wall behind, in St Petersburg, Russia

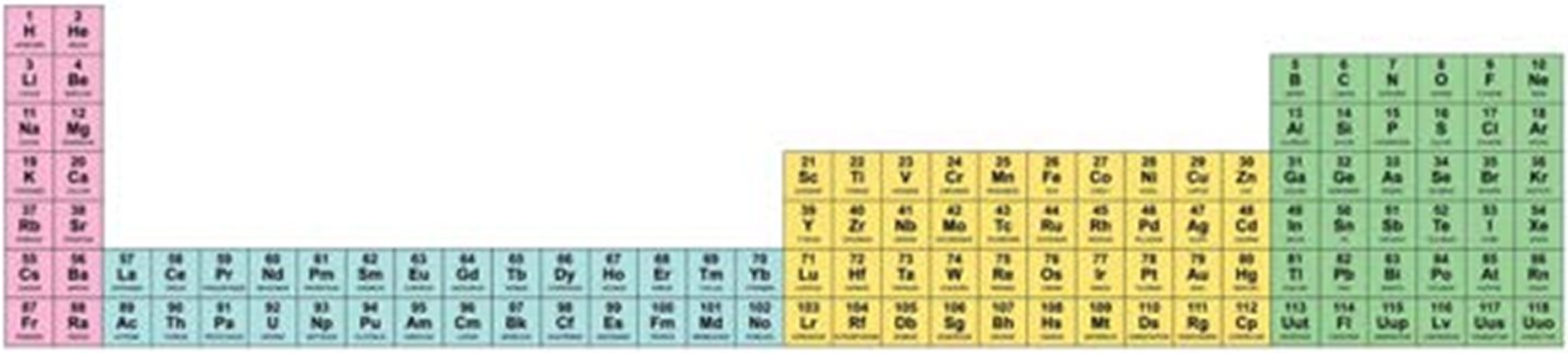


Figure 3.6 The long form periodic table. It is worth noting that the final resting place of La and Ac is currently under debate; while traditionally displayed in group 3, under Sc and Y, more recent debate has stipulated that the whole lanthanoid and actinoid group should come before group 3, and that this actually consists of the elements Sc, Y, Lu and Lr.

The modern periodic table is based on the 1869 periodic table of Dmitri Mendeleev. While Mendeleev's table arranged the elements in order of their atomic mass, the modern periodic table is based on increasing atomic number. Arranged in this way, elements in the same group have similar general properties and, moving from left to right across the periodic table, changes in the properties of the elements can be seen. The names of the key groups in the periodic table in Figure 3.2 are:

- group 1 – alkali metals
- group 2 – alkaline earth metals
- group 17 – halogens
- group 18 – noble gases
- the elements in the rectangular block that sits between group 2 and group 13 are called the transition metals
- the two rows at the bottom of the periodic table are called the lanthanoids and actinoids, respectively. These should sit in the top part of the periodic table but this would make the table long and less easy to use so they tend to be removed and kept separate. A 'long' periodic table is shown in Figure 3.6.

The majority of elements are metals (found on the left and in the centre of the periodic table). Other elements are classified as non-metals (on the right, with the exception of hydrogen, which is either placed on the left or separate to the other elements in the centre) and metalloids (forming a staircase between the metals and non-metals). Metals can be distinguished from non-metals by their physical properties. These are summarized in Table 3.2.

The metalloids show physical properties of both the metals and non-metals.

Physical properties of metals	Physical properties of non-metals
solids (except for mercury which is a liquid at room temperature)	solids or gases (except for bromine which is a liquid at room temperature)
shiny	solids are dull
good conductors of heat and electricity	non-conductors of heat and electricity
malleable (can be hammered into shape without breaking)	solids are brittle
ductile (can be drawn into long thin wires)	
usually hard but can vary	solids are soft
hard metals are sonorous (make a ringing sound when struck)	
usually high melting and boiling points but can vary	low melting and boiling points

Table 3.2 Summary of the differences in the physical properties of metals and non-metals

Figure 3.7 Some common metals

EXTENSION: GOING FURTHER

As we saw in Table 3.2, non-metals exist in either the gaseous or solid state at **standard ambient temperature and pressure (SATP)** (25 °C and 100 kPa). Hydrogen is a gas at SATP and a gas in space, so can you imagine the existence of a black flowing river of liquid hydrogen? While hydrogen exists in the gaseous form here on Earth, in the extreme conditions on Jupiter, there is evidence that it could exist in an entirely different state. Find out more here: **https://science.nasa.gov/science-news/science-at-nasa/2011/09aug_juno3**

Periodic table alter egos – what other information are they hiding?

■ **Figure 3.8** Copper has antiseptic properties and was used by the ancient Egyptians and Greeks to store water. It is now the metal of choice to create air conditioning wires.

■ **Figure 3.9** Titanium is used to make the parts for hip replacements because it bonds to our cells as if it were bone and our immune system does not attack or reject it.

■ **Figure 3.10** Tantalum is a metal that is mined and used to make mobile phones. In Chapter 12, you will find out more about how it is linked to the civil war in the Democratic Republic of the Congo.

■ **Figure 3.11** Cadmium is found underneath zinc in the periodic table and therefore displays similar properties. Our bodies are unable to distinguish between the elements and happily mop it up. But cadmium softens the bones to such a degree that they can snap when touched, leading to a disease called 'itai-itai' or 'ouch ouch' disease.

■ **Figure 3.12** Read about Graham Frederick Young, a British serial killer who used thallium to kill his victims, by searching for **Bismuth: A gentleman among scoundrels**.

■ **Figure 3.13** Alexander Litvinenko lost all his hair and his organs started to fail days after being poisoned by the element polonium, which led to his death a few days later.

How do scientists use trends and patterns?

EXPLANATION GAME

I notice that the atomic radius of group 1 metals increases going down the group.

Why is it this way?

Hint

Some of the terms that were used to describe the change in atomic radius across a period will be useful here.

Periodicity

In this section we are going to look more closely at our periodic table, in order to gain a better understanding of the significance of the arrangement of the elements and how this leads to periodic trends (trends that occur at regular intervals). **Periodicity** is the study of these trends and patterns arising from the arrangement of the elements in the periodic table.

Across a period

As we move across the periodic table from left to right, there is a clear change from metallic to non-metallic character in the elements. This is best seen in period 3, sodium to argon. The metals, sodium, magnesium and aluminium, are separated from the non-metals, phosphorus, sulfur, chlorine and argon, by the element silicon. Silicon is a metalloid, showing the properties of both metals and non-metals.

A further change going across the periodic table is a decrease in **atomic radius**. The radius of an atom depends on two competing factors, one attractive and one repulsive.

- The **nuclear charge** is the attraction between the positively charged protons and the negatively charged electrons. The greater the number of positive protons present in the nucleus of an atom, the greater the attraction, so the valence electrons are drawn inwards.
- The **shielding**/**screening** effect is the repulsion between the negatively charged electrons. The greater the number of completed shells of electrons, the more the attractive charge of the protons is reduced, allowing the valence electrons to move further away from the nucleus.
- The **effective nuclear charge** is the difference between the attractive force (nuclear charge) and the repulsive force (shielding effect).

As you move from left to right across a period, the attractive force (nuclear charge) increases as a proton is being added to the nucleus each time. However, because each additional electron is being added to the same shell as the previous one, there is no increase in the repulsion or shielding effect of the valence electrons. The result is that the effective nuclear charge increases, drawing the valence electrons closer to the nucleus and reducing the size of the atomic radius.

Group chemistry

When talking about elements in the periodic table, we usually refer to elements of a particular group. You can almost imagine that the elements within a group are close relatives of each other, like siblings in one big family. They share similar traits that make it clear they belong to the same family, but each sibling has their own character. Let's find out more about these 'families'.

ACTIVITY: Alkali metals and halogens (demonstrations)

ATL

- Information literacy skills: Collect, record and verify data
- Critical-thinking skills: Draw reasonable conclusions and generalizations; Identify trends and forecast possibilities

Demonstration: reaction of alkali metals with air and water

You will be observing the reactions of the alkali metals lithium, sodium and potassium with air (oxygen) and water in order to **identify** similarities in their physical and chemical properties, and highlight some trends and patterns within the group.

Safety: The demonstrator must wear safety goggles or a face shield and students must be at least 2 m away and wear safety goggles. Lithium, sodium and potassium are all corrosive and highly flammable, so the demonstrator must wear gloves and only very small pieces of the metals should be added to water. A scalpel should be used to cut pieces approximately 5 mm, 4 mm and 3 mm for lithium, sodium and potassium, respectively, from the larger pieces in the jars of oil, and any remaining metal returned to the jar immediately. Universal indicator can also include flammable substances.

Alternatively, you can watch this video: https://youtu.be/0KonBvfnzdo

1. **Draw** a suitable table into which you can record your observations.
2. **Describe** the appearance of the alkali metals and the ease with which they can be cut with a knife.
3. Observe what happens when the alkali metals are left exposed to air and **describe** your observations in your table.
4. **Deduce** a general word equation for the reaction of alkali metals with oxygen.
5. Observe what happens when the alkali metals are added to water and **describe** your observations in your table. What happens when universal indicator is added to the resulting solution?
6. **Deduce** a general word equation for the reaction of alkali metals with water.
7. **Outline** the similarities in the metals lithium, sodium and potassium.
8. **Describe** how the reactivity of the metals changes going down the group.
9. Use your observations to **suggest** how you would expect rubidium and caesium to react with water.

Demonstration: displacement reactions of the halogens

You will be observing the reactions of chlorine water, bromine water and iodine, with solutions of the halogen salts, sodium chloride, sodium bromide and sodium iodide, in order to **identify** trends and patterns within the group.

Safety: Safety goggles should be worn by the demonstrator and students. Chlorine water and bromine water are harmful; chlorine gas, which can escape during the demonstration, is toxic. The solutions of chlorine water and bromine water should be diluted to 0.1 per cent to minimize the production of chlorine and bromine fumes but still achieve a colour change; a 0.1 M iodine solution can be used. Stoppered test tubes should be used.

Alternatively you can watch this video of the reactions of the halogens with the halogen salts: https://youtu.be/HW2jRyQ3dzo

1. **Draw** a suitable table into which you can record your observations.
2. **State** the initial colours of the halogens in your table.
3. Observe what happens when the halogens are added to the salt solutions of the other halogens and **describe** your observations in your table.
4. Where a reaction was observed, **deduce** a word equation.
5. **Describe** how the reactivity of the halogens changes going down the group.
6. Fluorine is extremely reactive so cannot be used in the lab and astatine is a dangerous and highly radioactive rare element so is not well explored. However, we can use observations and patterns to make assumptions about some of their properties. **Suggest** what the colours of fluorine and astatine might be. **Suggest** how you would expect each of them to react with a solution of sodium chloride, sodium bromide and sodium iodide.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding and Criterion C: Processing and evaluating.

ALKALI METALS (GROUP 1)

The naturally occurring group 1 metals are all light-grey or silvery but do not share all the typical physical properties of metals; they are soft (can be cut with a knife), are not dense (they float on water) and also have relatively low melting and boiling points, which decrease going down the group. However, it is these common characteristics that result in them being grouped together. Chemically, they are highly reactive and have to be stored in oil to prevent them from reacting with the oxygen or water vapour in the air, therefore they are never found as pure elements in nature. They also react with the element sulfur and with the halogens. Adding them to water makes hydrogen and an alkaline solution (the metal hydroxide) which is where they get their group name from. Their reactivity increases going down the group. The final element in the group, francium, barely exists in nature and is extremely radioactive, so is only found in laboratories where it can be made.

■ **Figure 3.14** The alkali metals need to be stored in oil to prevent them from reacting with the oxygen in the air

■ **Figure 3.15** The halogens in gas jars: fluorine, chlorine, bromine and iodine

Hydrogen gas is one of the products of the reaction of the alkali metals with water. The test for hydrogen gas is called the 'squeaky pop' test; if a lighted splint burns with a squeaky pop, it confirms the production of hydrogen gas. Can you write a word equation for this reaction?

Alkali metal compounds are used widely in manufacturing and industry. Sodium chloride is table salt, sodium bicarbonate is used in baking, and one of the main ingredients in gunpowder is sodium nitrite. Other compounds of sodium are used in the paper and pulp industry, while sodium carbonate removes sulfur dioxide from emission stacks. Compounds of potassium are found in the manufacturing of fertilizers as well as in detergents, explosives and in the photographic industry.

HALOGENS

The group 17 non-metals are all coloured substances (getting progressively darker from pale yellow to yellow-green to red-brown to deep purple), poisonous and have a very strong smell. They have low boiling points and show a change of state from gases (fluorine and chlorine) to liquid (bromine) to solid (iodine) going down the group. The halogens exist as **diatomic** molecules and dissolve in water to form strong acids. They are extremely reactive, with reactivity decreasing down the group. The earlier demonstration proved this, showing that a more reactive halogen was able to displace a less reactive halogen from its solution. This is called a displacement reaction. As discussed above, the halogens react directly with metals, in particular alkali metals, to form salts called halides.

Halogens are used as bleaching agents as they can remove colour; chlorine, for example, is used to make white paper. They are also disinfectants; chlorine is added to drinking water and to swimming pools to kill bacteria. When chlorine is dissolved in sodium hydroxide it forms sodium chlorate (I) which is found in domestic bleach. Fluorides are added to water and toothpaste to reduce tooth decay. Bromine is used to to make plastics and pesticides, as well as sedatives.

DISCUSS

What will happen to the atomic radius of group 17 elements going down the group?

DISCUSS

Why do the noble gases exist as **monatomic** atoms? Why was the group previously called group 0?

Iodine is used in antiseptics (it is less strong than a disinfectant and can be added to the skin) for sterilizing wounds. It is also a vital ion in our diet as it is used to make the hormone thyroxine which controls the body's metabolic rate.

Links to: Language and literature

Exploring science through literature allows us to describe science in a new language and experience it from a different perspective.

Use this website to find the poem *Dulce et decorum est* by Wilfred Owen, which was published after he died during the First World War: **www.wilfredowen.org.uk/poetry/dulce-et-decorum-est**

Aimed at people who thought war was noble and glorious, it describes the true horrors of war, and in particular the effects of the use of chlorine gas which was used for the first time as a chemical weapon in this conflict (find more on the uses of gases in war in Chapter 11).

Links to: Individuals and societies

Science has played a significant role in many historical events that are explored through the subject of Individuals and societies. Whether it be civil wars in order to obtain natural resources, or the use of ammunition and chemicals in global wars, in the last century governments spent an incredible amount of money on enlisting the help of scientists. Some scientists have knowingly contributed to warfare, while for others their work has been used in ways they could not even imagine. What responsibility do scientists have for the consequences of their discoveries? We will be exploring this topic further in Chapters 10 and 11.

NOBLE GASES

The final group in the periodic table, the noble gases (group 18), are all present in the Earth's atmosphere with argon occurring in the greatest proportion (about 0.9 per cent). Helium is the second most abundant gas in our Universe, after hydrogen. The noble gases are colourless, odourless, tasteless and non-flammable. Their full shells and resistance to bonding make them extremely unreactive or **inert** (though more recently it has been shown that, on occasion, they can form compounds under extreme conditions). This is the reason why they are the most recently discovered group of elements and why this whole group of elements was left out of Mendeleev's periodic table.

The uses of the noble gases are centred around their properties. Helium is used in balloons because it is less dense than air and in spacecraft as it is unreactive. It is also used in deep-sea diving to reduce the proportions of oxygen and nitrogen to below those in air, which reduces the narcosis effect of nitrogen. All of the noble gases glow when an electric charge is passed through them, so they are commonly used in advertising signs. Argon is the gas used to fill traditional hot **filament** light bulbs; the hot filament (thin metal wire) would normally react with any gas present but by surrounding it with an unreactive gas this is prevented. Krypton, along with neon and xenon, is used in lasers.

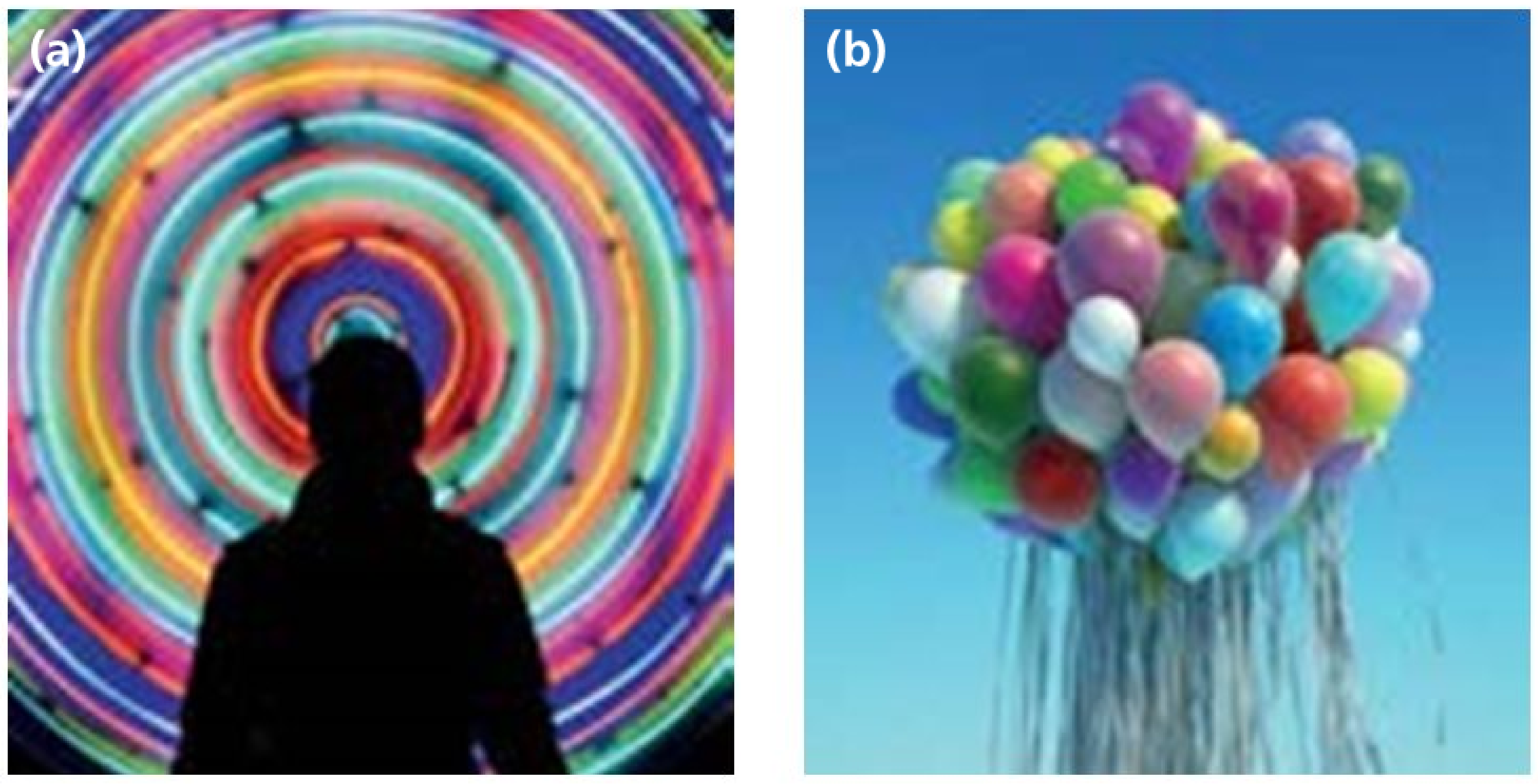


Figure 3.16 (a) Noble gas elements are used in advertising, (b) helium is used in balloons

THINK–PAIR–SHARE

Individually, consider whether it is a coincidence that the least reactive group, the noble gases, is found between the two most reactive groups, the alkali metals and the halogens.

With a partner, **compare** and **contrast** the physical and chemical properties of group 1, group 17 and group 18 elements.

As a class, **discuss** which group you feel is the most useful, making reference to the use of the elements in your everyday lives.

TRANSITION METALS

The transition metals sit in a block in the middle of the periodic table. Most of the important metals that we rely on are found within this section of the periodic table, including iron, copper, silver and gold.

DISCUSS

The general properties of metals that we described earlier on in this chapter are very typical properties of the transition metals. Make a list of these key properties or review your learning from earlier if you need a reminder.

The transition metals are different from the metals of group 1 and group 2 in two main ways: they are nowhere near as reactive, which is what makes them so much more useful, and they form coloured compounds. This property can be used decoratively; for example the colours in stained glass are often created using transition metals. Figure 3.17 shows images of some transition metal compounds. Transition metals also have high densities and high melting and boiling points and are often used as catalysts (Chapter 10) to speed up chemical reactions.

EXTENSION: GOING FURTHER

Zinc is not actually classified as a transition metal. Understanding the reason behind this is beyond the scope of this book, however if you can't wait until DP Chemistry, carry out some research to try to find out why. It will require you to rethink the electron arrangements of the elements.

Figure 3.18 summarizes key trends going down groups and across periods in the periodic table.

PATTERNS IN REACTIVITY

We have seen that there is a direct link between the chemical properties of an element and its position in the periodic table. Why do elements in the same group react similarly? Why does the reactivity of metals increase going down the group? How would the reactivity change from group 1 to group 2? Why does the reactivity of the non-metals decrease going down the group? All of these clear patterns can be explained by understanding the driving force behind reactions, and to do this we need to revisit electron arrangements.

■ **Figure 3.17** Transition metal compounds: (a) copper (II) sulfate, (b) potassium permanganate, (c) cobalt (II) chloride

ACTIVITY: Patterns in reactivity

ATL

- Communication skills: Make inferences and draw conclusions
- Creative-thinking skills: Apply existing knowledge to generate new ideas, products or processes

Identifying trends in the reactivity of metals

1. **List** the symbols of the metals lithium, sodium and potassium and **state** their electron arrangements.
2. **List** the symbols of the metals beryllium, magnesium and calcium and **state** their electron arrangements.
3. **Describe** any patterns you observe in the electron arrangements of the metals in the two groups.
4. According to the octet rule, atoms of elements 6–20 tend to combine in a way that results in their atoms having eight electrons in their valence (outer) shell, thereby achieving a full outer shell. This is because full shells make the atom electronically stable. **Suggest** how the electron arrangement of the element will change when each of the metals above reacts.
5. **Suggest** reasons why the reactivity of metals increases going down the group.
6. **Suggest** how the reactivity of the metals changes moving from group 1 to group 2, justifying your answer.

Identifying trends in the reactivity of non-metals

1. **List** the symbols of the non-metals fluorine and chlorine and **state** their electron arrangements.
2. **List** the symbols of the non-metals oxygen and sulfur and **state** their electron arrangements.
3. **Describe** any patterns you observe in the electron arrangements of the non-metals in the two groups.
4. **Suggest** how the electron arrangement of the element will change when each of the non-metals above reacts, taking the octet rule into consideration.
5. **Suggest** reasons why the reactivity of non-metals decreases going down the group.
6. **Suggest** how the reactivity changes moving from group 16 to group 17.
7. **Explain** why the noble gases are completely unreactive.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

LINKING POSITION IN THE PERIODIC TABLE AND ELECTRON ARRANGEMENT

The activity *Patterns in reactivity* has shown that elements in the same group of the periodic table have the same number of valence electrons. Further, for the elements in groups 1–2 and 13–18 (the main group elements), the number of valence electrons can be linked to the element's position in the periodic table – to the group number:

- for the metals: number of valence electrons = group number
- for the non-metals: number of valence electrons = group number – 10.

The number of shells of electrons an atom has can also be linked to its position in the periodic table as the number of shells is the element's period number.

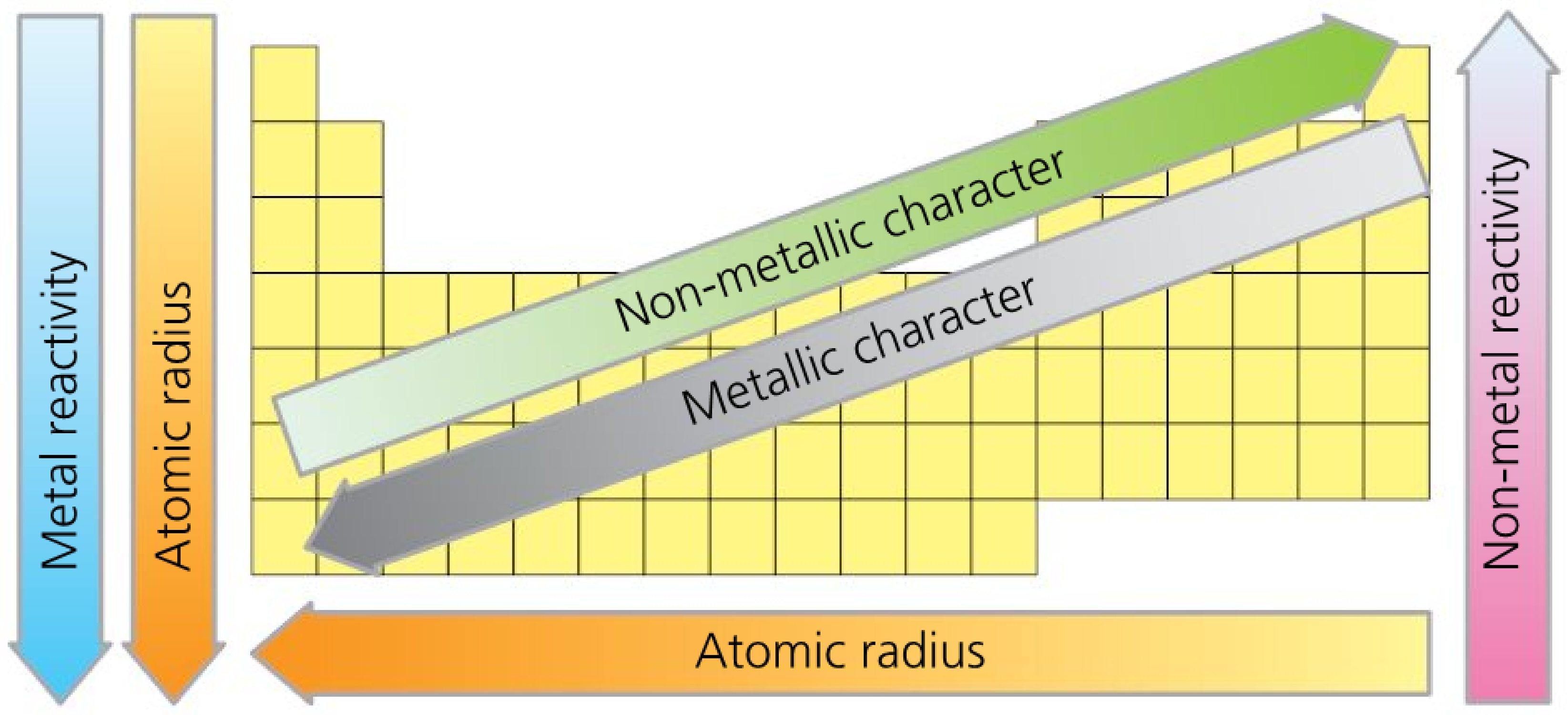


Figure 3.18 Trends in the periodic table

FORMING IONS

When metals react, they lose electrons in order to have complete shells. When electrons are lost, the resulting particle, an ion, has a positive charge and is known as a **cation**. The number of electrons lost is equal to the positive charge on the ion.

When non-metals react, they gain electrons in order to complete their shells. When electrons are gained, the resulting particle, an ion, has a negative charge and is known as an **anion**. The number of electrons gained is equal to the negative charge on the ion.

The chemical properties of an element depend on the number of valence electrons it has. As elements in the same group have the same number of valence electrons, they will have similar chemical properties.

For metals, the ease with which the valence electrons are lost is what determines the reactivity; the more easily they are lost, the more reactive the metal. For non-metals, the ease with which electrons are gained to complete the valence shell is what determines reactivity; the more easily electrons can be gained, the more reactive the non-metal.

The ease with which the valence electrons can be lost or gained depends on the two competing factors: attraction between the protons and electrons (nuclear charge) and repulsion between the negatively charged electrons (the shielding effect).

■ **Figure 3.19** Remember CATions are PAWsitively charged

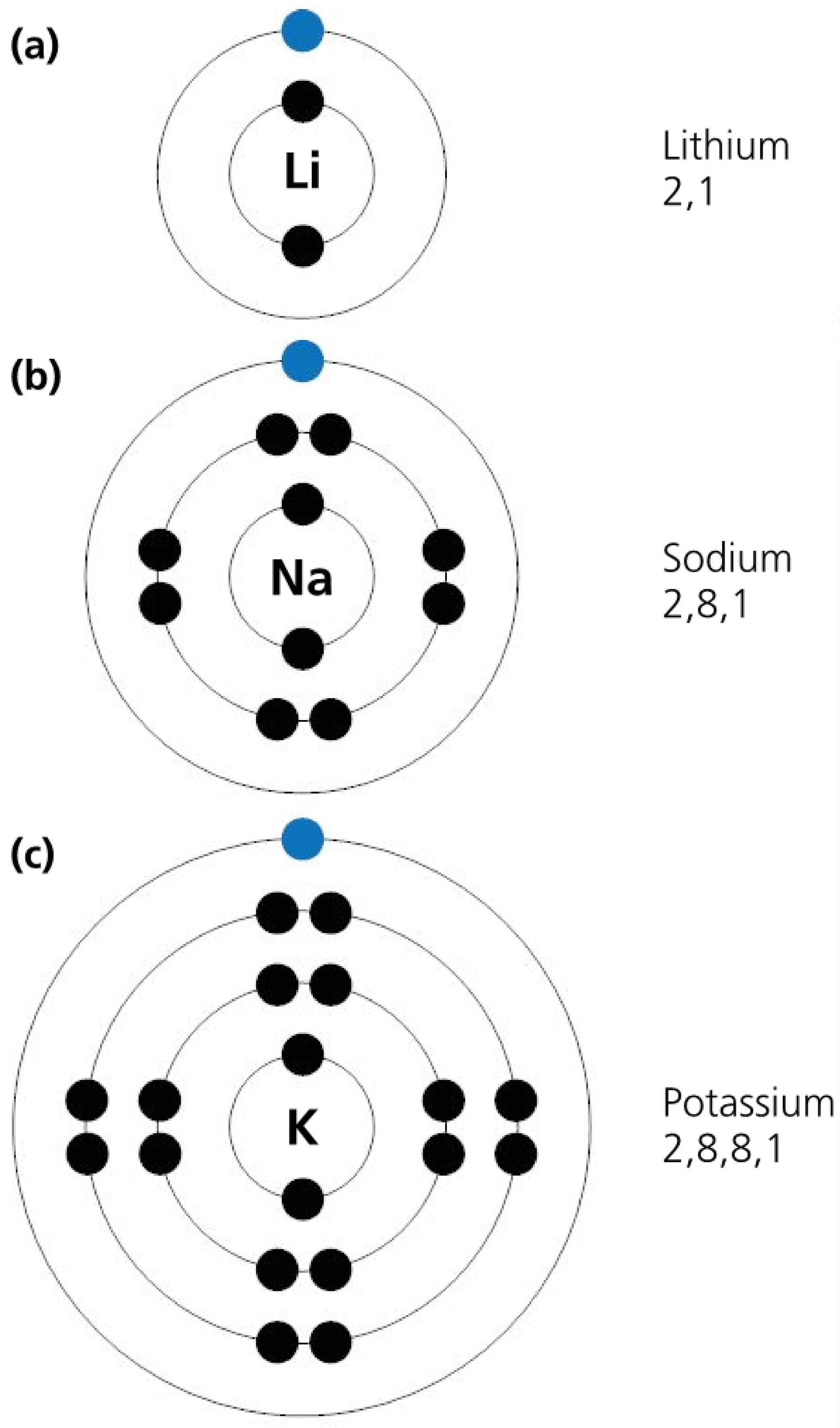
EXTENSION: GOING FURTHER

Return to the *Build an atom* simulation (Chapter 2, page 29). Use the information on your periodic table to create a neutral atom for all of the elements from hydrogen to neon, each time experimenting by adding or removing electrons until an ion is formed with full shells. Record the overall charge on each of the ions formed. Compare this to the element's group number. Does this agree with the rule on page 59?

EXPLANATION GAME

I notice that the reactivity of group 1 metals increases going down the group. Why is it this way?

I notice that the reactivity of group 17 non-metals decreases going down the group. Why is it this way?



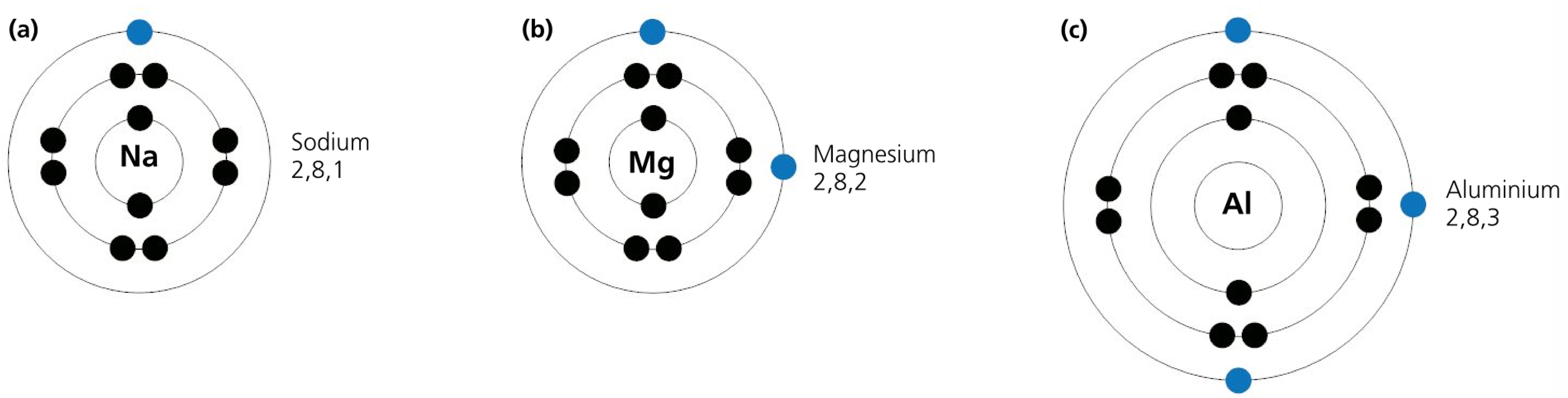
■ **Figure 3.20** The electron shell diagrams of (a) lithium, (b) sodium, (c) potassium

As you go down a group, there are more protons in the nucleus which increases the nuclear charge and therefore the attraction of the valence electrons. However, each time you go down the group, you add a full shell of electrons which increases the repulsion between the electrons and thus the shielding effect between the nucleus and the valence electrons. The increasing shielding effect has a greater impact than the increase in the nuclear charge, which means that the further down the group you go, the attraction between the nucleus and the valence electrons is weaker. In the case of metals, it means the valence electrons are more easily lost and the metals are more reactive. In the case of non-metals, the pattern is reversed as further down the group, weaker attraction means it is harder to gain electrons, so the non-metals become less reactive.

The trend in reactivity of both the metals and non-metals can be linked to the trend in atomic radius, which also depends on the competing effect of nuclear charge and shielding. The further away from the nucleus that the valence electrons are, the more easily they are lost, or the less easily they are gained. So as you go down a group and the atom gets larger, the more reactive it is if it is a metal and the less reactive it is if it is a non-metal.

CONNECT–EXTEND–CHALLENGE

Figure 3.21 shows the electron shell diagrams for sodium, magnesium and aluminium. Place the metals in order of reactivity, explaining why you have decided on this particular order.



■ **Figure 3.21** The electron shell diagrams of (a) sodium, (b) magnesium, (c) aluminium

How are the ideas and information presented **connected** to what you already knew?

What new ideas did you come up with that **extended** or pushed your thinking in new directions?

What is still **challenging** or confusing for you to get your mind around?

What questions, wonderings or puzzles do you now have?

To what extent does classification help or restrict our understanding of new information?

THE PERIODIC TABLE

Mendeleev's periodic table opened a door to a new level of understanding of the elements and of chemistry. It made links which were previously unknown and allowed predictions to be made about both the physical and chemical properties of undiscovered elements. Accurate predictions about the properties of elements can be made just by looking at their position in the periodic table and we use our knowledge of these properties for new inventions (for example rare earth metals are used in alternative technologies for new ways to make energy).

So why was Mendeleev's classification system more successful than the attempts of other scientists? A classification system needs to have some flexibility so as not to restrict our understanding of new information. Newlands and Döbereiner had failed in their attempts to classify the elements, as they did not possess the open-mindedness of Mendeleev, who acknowledged that he might not have all of the information that he needed to create a complete periodic table at the time.

But is this version of the periodic table the best there is? Consider the following questions:

- Where should hydrogen be placed in the periodic table? Should it be placed above the group 1 alkali metals as it is in many periodic tables?
- Does helium deserve to be in group 18, as it only has two electrons in its outer shell while the rest have eight?
- Does the removal of the lanthanoids and actinoids aid or inhibit our understanding of the changing properties of the heavier elements?

There has been much controversy concerning the placement of lanthanum, the first of the lanthanoid elements, and actinium, the first of the actinoid elements. Typically, they have been placed in group 3, underneath scandium and yttrium, but, as mentioned earlier on in this chapter, more recently, lutetium and lawrencium have taken their place in the bottom of group 3 and lanthanum and actinium have been moved to the two rows that sit beneath the periodic table with the rest of the lanthanoids and actinoids.

There have been hundreds of alternative periodic tables suggested. (Mendeleev alone put forward about 30.) Figures 3.22–3.24 show just a few.

We have seen how identification of *pattern* and of *form* has enabled scientists to classify non-living matter in terms of the *relationships* between elements. Now we will consider how the same concept can be applied to living matter.

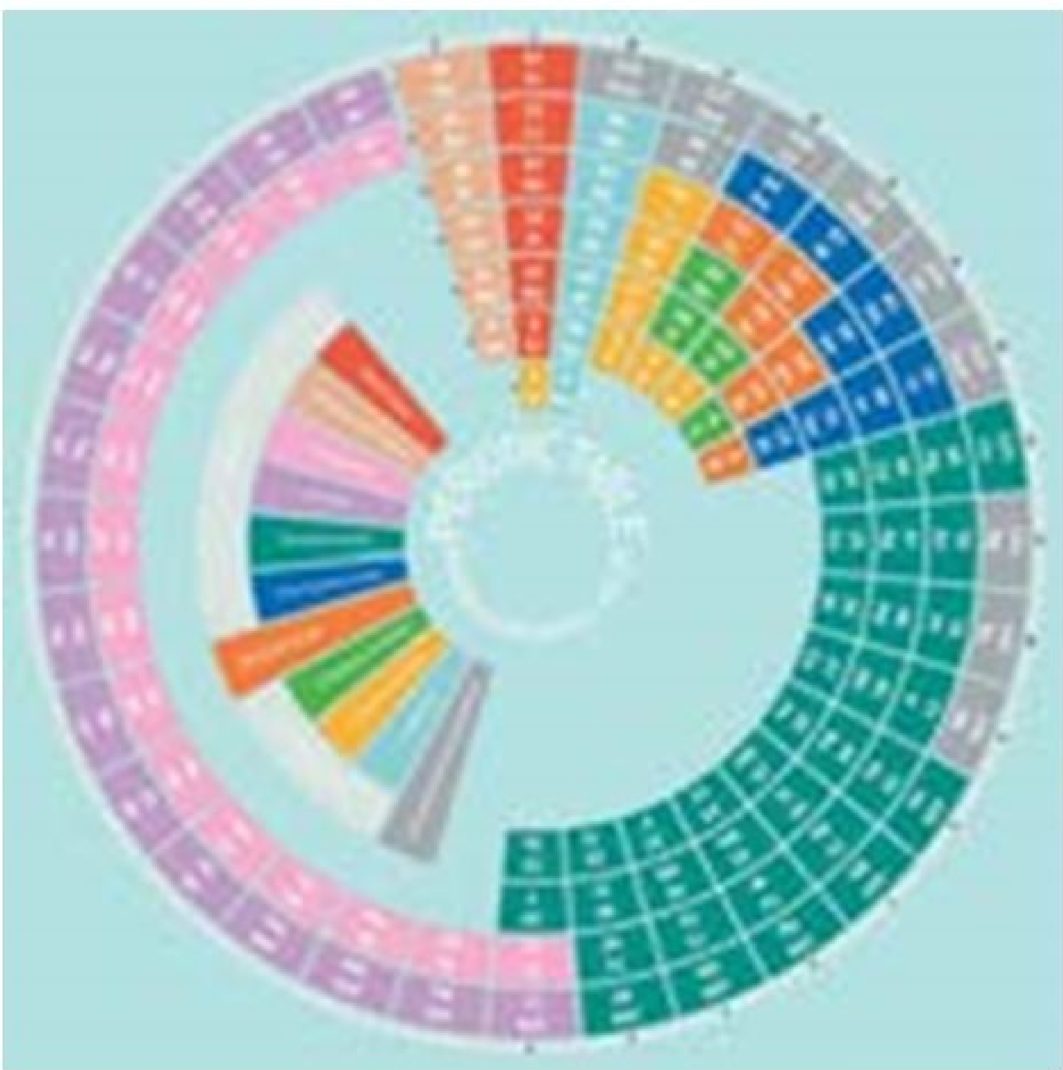


Figure 3.22 Charles Janet's left-step periodic table in a spiral version (1929)

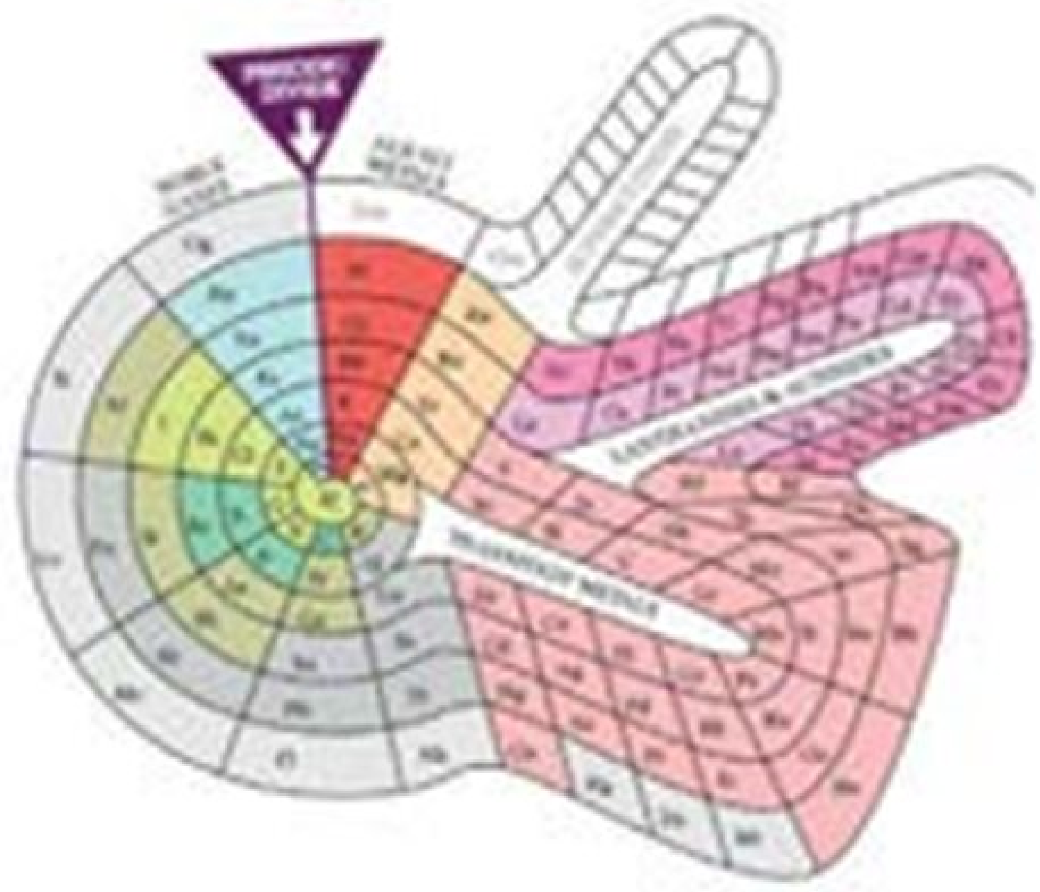


Figure 3.23 Theodor Benfey's spiral periodic table (1964)

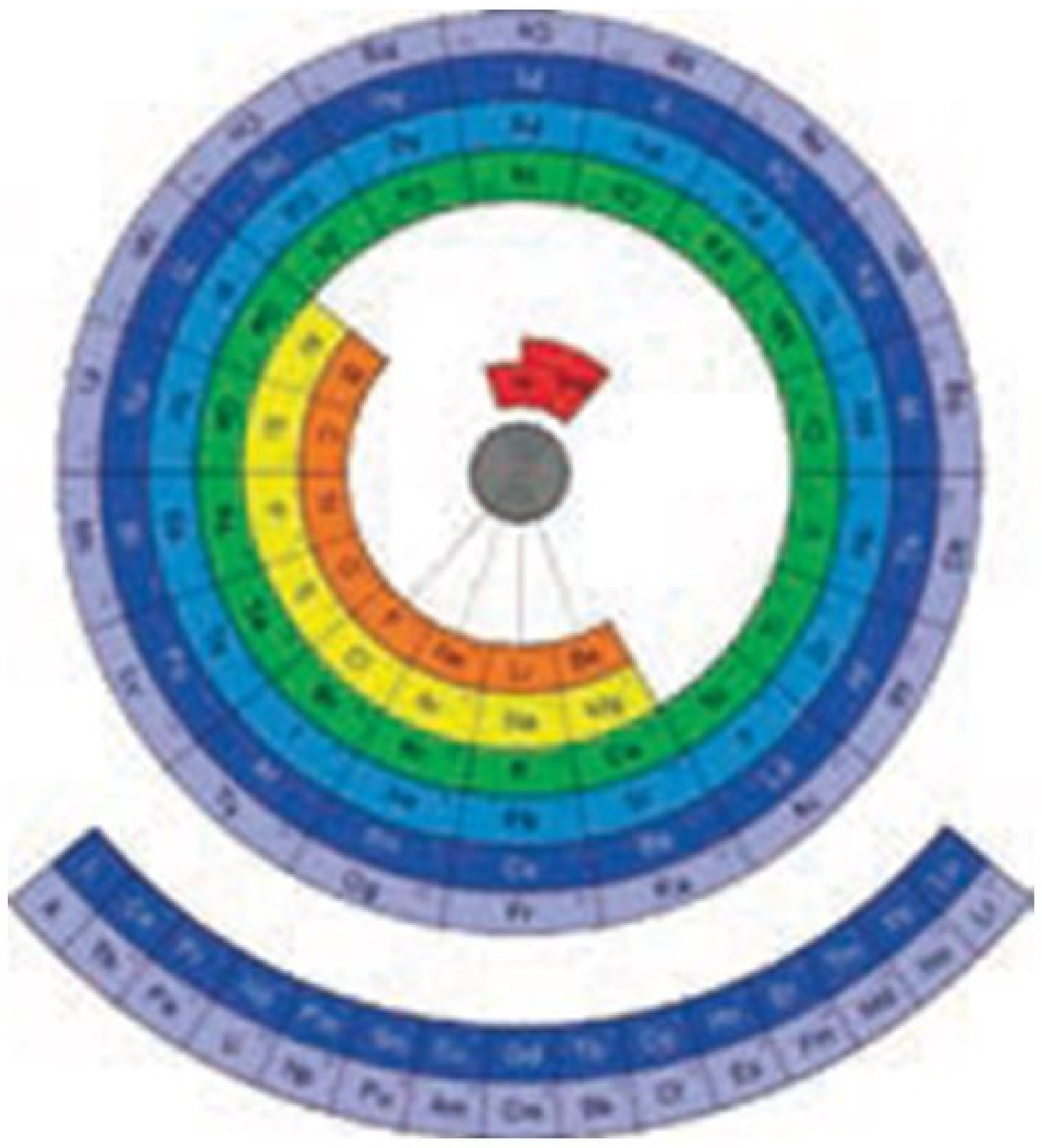


Figure 3.24 A circular periodic table

How are characteristics of living things used to classify them?

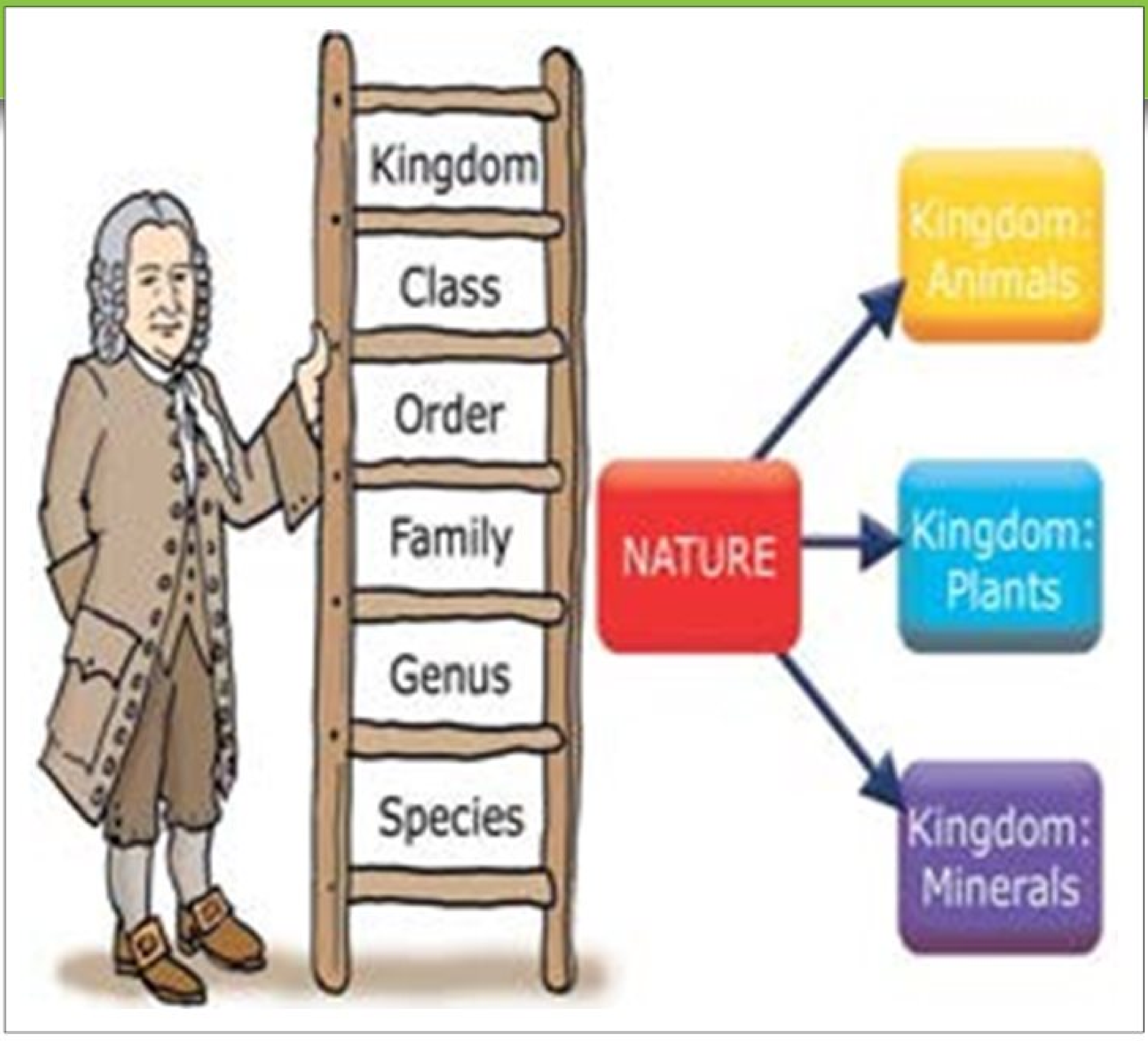


Figure 3.25 Linnaeus' classification of nature (right). Further lower level categories were introduced (left). 'Minerals Kingdom' has since been abandoned.

WHAT MAKES YOU SAY THAT?

Look for pictures of a **great grey owl**, a **red fox** and a **long-nosed bat**. Which of these animals is the odd one out? What makes you say that? **Discuss** your answer with the rest of your class.

Imagine you are asked to tidy a room full of clothes and objects in no particular order. Instinctively, you would probably start to group these items into categories based on their similarities and differences. While you may choose a certain way of organizing these items, such as by type of material or colour, someone else might decide to organize them by size or usefulness. There is a huge amount of diversity in nature; no one knows the exact number of different living things that ever existed on Earth. Organizing them is what scientists tried to do using observations of similarities and differences in key characteristics. The science of classifying living things is called **taxonomy**. As in our room example, scientists do not always agree on certain details when grouping living things. The most influential scientist whose classification system and ideas are still being used nowadays is Carl Linnaeus (1707–78). He is called the 'father of modern taxonomy'. In his publications, he described his system of naming living things and organizing them into hierarchical groups.

Let's use the example of the teaching groups in a particular school. Your school might include three smaller schools (e.g: primary, secondary and college). Each of these will be divided into further sections, for example the secondary school might be divided into upper and lower school, then each will be subdivided into classes and so on until you reach the level of individual students! Similarly, Linnaeus classified nature by first splitting it into three **kingdoms**: animals, plants and minerals. He then introduced lower-level categories such as class, order, genus and species to group living things. These categories enabled Linnaeus to create a **nomenclature** for naming each individual species. His system is called the **binomial** system since it gives each living organism a name composed of two parts. As many people have a forename and a family name, so the lion will be called *Panthera leo*, for example.

This universal system allows scientists, regardless of their language, to avoid any confusion when talking about a particular organism. The first part of the name indicates the genus and the second part indicates the species. A genus is a group of similar species; a species is a group of organisms that share similar characteristics and can mate to make fertile organisms of the same species. Humans who currently live on Earth all belong to the same species, *Homo sapiens*, but other species of humans such as *Homo neanderthalensis* have existed and there is evidence that they interbred with modern humans but became extinct.

Latin or ancient Greek names are used to describe taxonomic groups or species. It is an international convention that the genus starts with an uppercase letter and the species with a lower case letter. They should both be written in *italic* when printed or underlined when handwritten.

As mentioned, two individuals belonging to different species cannot normally **interbreed**. If they do, their offspring are usually infertile and unable to reproduce. For example animals called mules are the offspring of a male donkey and a female horse. Because horses and donkeys are different species, mules are infertile and acquire a number of chromosomes that does not allow them to reproduce. Table 3.3 on page 65 shows how humans and onions are classified following a Linnaeus-inspired system of classification.

How have technological advances affected our models of the world?

Traditional classifying methods rely largely on observations of **morphological**, functional and anatomical characteristics of living things. Advances in technology meant that taxonomists had more powerful tools to enable them to look at living things in a different way. DNA sequencing techniques allow scientists to map out and compare the genomes of living organisms to find relationships between species that may have been considered distant relatives in the past. These findings have resulted in many changes in the traditional classification systems. Some species have been moved from one group to another and some categories or levels of classification have been introduced or changed. For example, we moved from the three kingdoms suggested by Linnaeus to five then six kingdoms. Higher classification groups called **domains** or **superkingdoms** have been created. The two superkingdoms are **Prokaryota** (which include bacteria) that have cells with no defined nucleus and **Eukaryota** which include all organisms that have cells with a defined nucleus and more complex structures. Eukaryota were then divided into four kingdoms: plants, animals, fungi and protista. In the 1990s, based on bacterial DNA studies and analysis, a scientist called Carl Woese suggested that there should be a third group separated from Prokaryota called **Archaea** because of the significant differences between archaebacteria and eubacteria. This resulted in what is now known as the three-domain system (Bacteria, Archaebacteria and Eukaryota). However, many scientists disagreed with this new rearrangement and continued to use the two domain system with Archaebacteria becoming a new kingdom separated from Bacteria.

These new scientific and technical developments mean that in addition to morphological and anatomical differences or similarities between living things, scientists now take into account the evolutionary history of the species they study. This approach is called **phylogenetics**. Therefore, when grouping species, we should not only look at **analogous features**, such as the presence of wings in birds and insects or the body shape of sharks and dolphins (which could simply be related to function rather than anatomy or origin), but also consider **homologous features** which indicate a common evolutionary origin. These considerations have given rise to **cladistic classification**. Cladistic classification traces the characteristics of organisms back to the most recent ancestor and scientists sometimes use **clades** rather than the traditional Linnaean divisions of class or phylum to describe groups of organisms.

It is now relatively easy to access online information about the latest agreed classification of all known species on Earth. Numerous databases are available to the public such as the ITIS (Integrated Taxonomic Information System) and 'Catalogue of Life' (CoL). As of April 2017, the CoL had 1.7 million species classified out of the 1.9 million species known to science (including extinct species). Can you imagine how Linnaeus would feel having such information at the tips of his fingers?

ACTIVITY: Who am I?

ATL

- Information literacy skills: Access information to be informed and inform others
- Media literacy skills: Locate, organize and use information from a variety of sources and media

In this activity, you will work in groups of 4–5 students and access various online sources to find the classification of organisms of your choice. You will then use the information to **construct** a quiz for the rest of the class.

- As a group, **select** five living organisms (preferably belonging to different kingdoms such as animals, plants, etc.) then **search** for their classification. Enter the search term catalogue of life then input the name of the organism you are searching for. If you don't find the classification, it could be because the database does not recognize the common name you used. In that case enter the common name in your browser followed by scientific name. When you find the scientific name of your organism, enter it in the database to find its full classification from domain to species. Use the empty column labelled 'Mystery organism' in Table 3.3 to **classify** your chosen organism.
- Add more columns for all of your chosen organisms as needed. Once done, use the classification of these organisms to **create** a quiz called 'Who am I?'. For example, **state** 'I belong to the superkingdom of Eukaryota, I am from the kingdom Animalia, I belong to the class of Mammalia …' and so on until you reach the genus and the species. Take turns with the rest of the groups, scoring points for each group that gets the correct answer then reveal the answers at the end.
- To make this activity even more interesting, you could add more hints in the form of unique characteristics about the organism in question to help your classmates in their guess.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

	ONION *Allium cepa*	HUMAN *Homo sapiens*	Mystery organism
SUPERKINGDOM	Eukaryota	Eukaryota	
KINGDOM	Plantae	Animalia	
PHYLUM	Tracheophyta	Chordata	
CLASS	Liliopsida	Mammalia	
ORDER	Asparagales	Primates	
FAMILY	Amaryllidaceae	Hominidae	
GENUS	*Allium*	*Homo*	
SPECIES	*cepa*	*sapiens*	

Table 3.3 Classification of humans and onions using the Catalogue of Life database

EXTENSION

Traditional taxonomy techniques are time consuming and difficult to use when scientists wish to quickly identify the species living in a particular habitat. Find out more about the exciting work of the scientists in the British Natural History Museum, who are using cutting edge technology to help them overcome what they called 'the taxonomic barrier': **www.nhm.ac.uk/our-science/our-work/biodiversity/breaking-the-taxonomic-barrier.html**

ACTIVITY: Plant detectives!

ATL

- Communication skills: Use and interpret a range of discipline-specific terms and symbols; Organize and depict information logically; Make inferences and draw conclusions
- Creative-thinking skills: Apply existing knowledge to generate new ideas, products or processes
- Collaboration skills: Give and receive meaningful feedback
- Information literacy skills: Collect and analyse data to identify solutions and make informed decisions

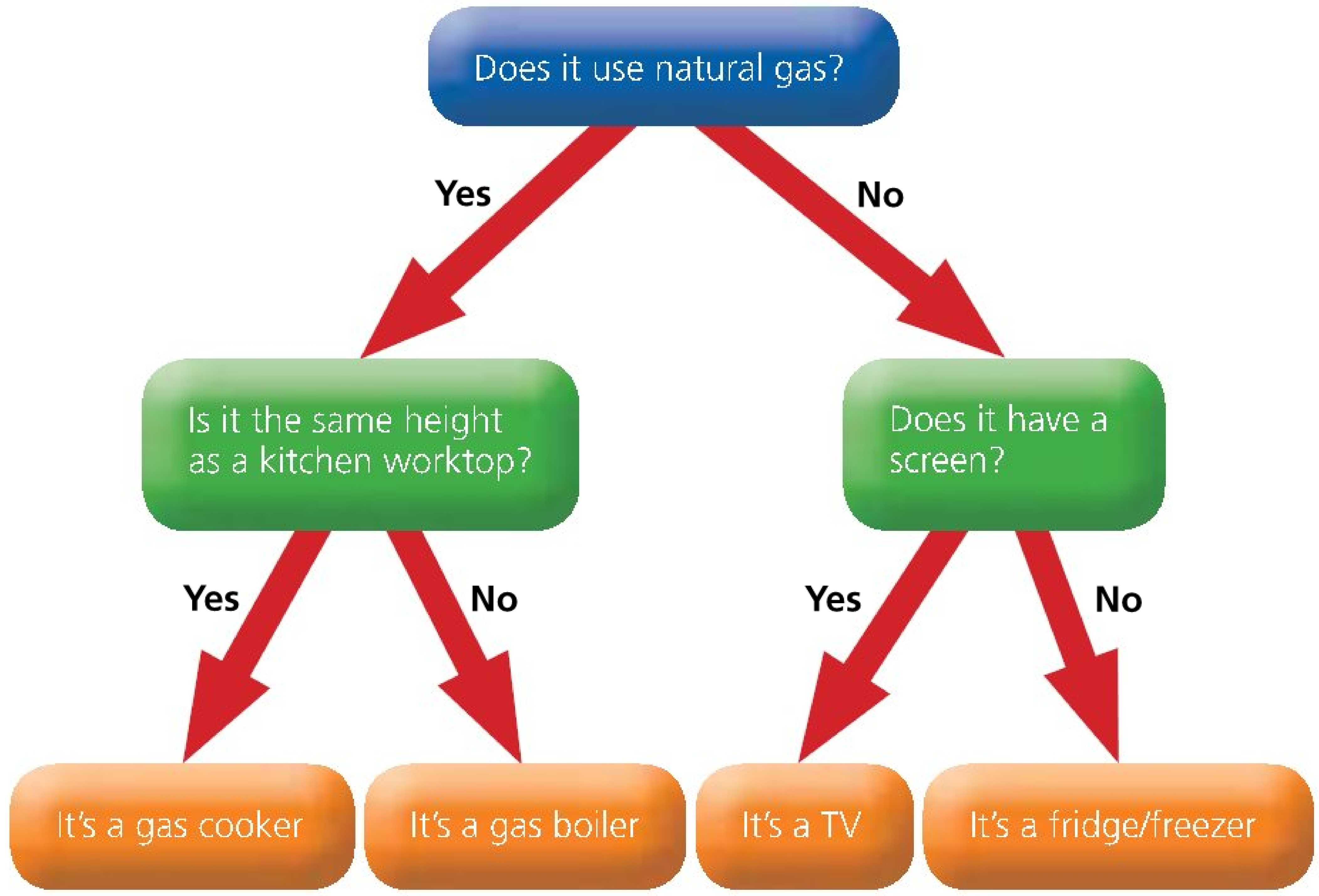


Figure 3.26 A simple dichotomous key to help identify household appliances

Imagine that you and your friend are nature explorers and your adventure landed you on an island with a variety of plants that you have never seen before. In your adventure bag you only have a camera, a magnifying glass, a pen and some paper. How would you **identify** these plants?

Scientists use what is called a key, more specifically a **dichotomous key**, to identify living things.

Look at the example given in Figure 3.26. This shows a very simple dichotomous key to identify household appliances. The same key can be written in a different way as shown in Table 3.4.

Description/question	Answers
1. Does it use natural gas?	Yes – Go to Question 2 No – Go to Question 3
2. Is it the same height as a kitchen worktop?	Yes – It's a gas cooker No – It's a gas boiler
3. Does it have a screen?	Yes – It's a TV No – It's a fridge/freezer

Table 3.4 Simple dichotomous key to identify household appliances

You can learn more by looking at other examples. Search **examples of dichotomous keys of plants, animals, insects** in your browser.

Work in groups of two to three students.

Part 1

Use the characteristics of some groups of plants to **design** a simple dichotomous key that will help you **classify** them into the suggested phyla and classes. (According to the Catalogue of Life, the plant kingdom contains eight phyla in total but we chose two for simplicity.)

Use this information to **construct** one type of key as suggested in Table 3.4 or Figure 3.26:

- **Phylum *Bryophyta* (mosses): plants with simple leaves and stems; small in size; no roots; have hairy structures called rhizoids instead; reproduce by spores stored in capsules**
- **Phylum *Tracheophyta* (vascular plants): land plants which contain transport systems with phloem to conduct products of photosynthesis throughout the plant and xylem containing lignin to transport water and minerals**

We will consider the following classes in the phylum Tracheophyta:

- **Class of *Liliopsida*: flowering plants; seeds only contain one embryonic leaf or cotyledon; leaves are narrow and linear with parallel veins; the leaves usually form a sheathing around the plant stem at its base; examples are rice, wheat, maize, sugar cane, onions and grasses**
- **Class of *Pinopsida*: most are evergreen, cone-bearing trees; they can grow very tall, up to 100 metres or more; leaves can be long, thin and resemble needles or can have a scaly structure; examples are pine trees, cedars and yew trees**

- **Class of *Magnoliopsida*: flowering plants; seeds contain two embryonic leaves; leaves are flat and vary in size but have reticulate veins branching from a central vein; examples include geranium plants, apple trees, lettuce and nettle plants**

Part 2

Once you have constructed your key, swap it with that of another group of students. Collect some plants from your school environment and bring them back to the classroom. Use the borrowed key to **classify** the plants you collected by **examining** them carefully using a magnifying glass if necessary.

Organize the data into a suitable form, perhaps as a table with a specimen or a picture glued next to the classification. **Evaluate** the efficiency of your key and that of your friends in classifying plants.

Suggest improvements to your friends' key. Ask for their feedback to improve your own key.

Describe what information you would need to **identify** which lower ranking groups the plants belong to, such as the family, the genus and the species.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion B: Inquiring and designing and Criterion C: Processing and evaluating.

Take action: Why classify?

ATL

- Information literacy skills: Access information to be informed and inform others; Make connections between various sources of information; Evaluate and select information sources and digital tools based on their appropriateness to specific tasks
- Critical-thinking skills: Gather and organize relevant information to formulate an argument

Figure 3.27 Why taxonomy matters!

- Having a unified approach to classifying living things makes communication between scientists and other communities easier. However, the importance of taxonomy goes beyond its use as a language of biodiversity.
- Your task is to write an article for a science magazine to debate an idea that was discussed in a previous issue in which they claimed that taxonomy is now 'old fashioned'.
- To begin, watch this video or search taxonomy, discover, nhm: **www.nhm.ac.uk/discover/naming-nature-putting-life-in-order.html**
- In your article:
  - **describe** and **explain** how taxonomy helps in the specific area or example you chose, focusing on the scientific facts
  - **discuss** and **evaluate** the implications of using taxonomy in the area you chose and other possible areas linked to society, the economy and the environment
  - **apply** scientific language and use visuals to support your arguments
  - **document** all of the sources using a recognized referencing and citation system.

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

(a) Siberian tiger, *Panthera tigris altaica* | (b) Domestic cat, *Felis catus* | (c) Lion, *Panthera leo*

(d) Bengali tiger, *Panthera tigris tigris* | (e) European gray wolf, *Canis lupus* | (f) Dog, *Canis lupus familiaris*

■ **Figure 3.28** Animals with their common and scientific names

SOME REVIEW PROBLEMS TO TRY

1 The scientific and the common names of some animals are shown in Figure 3.28.

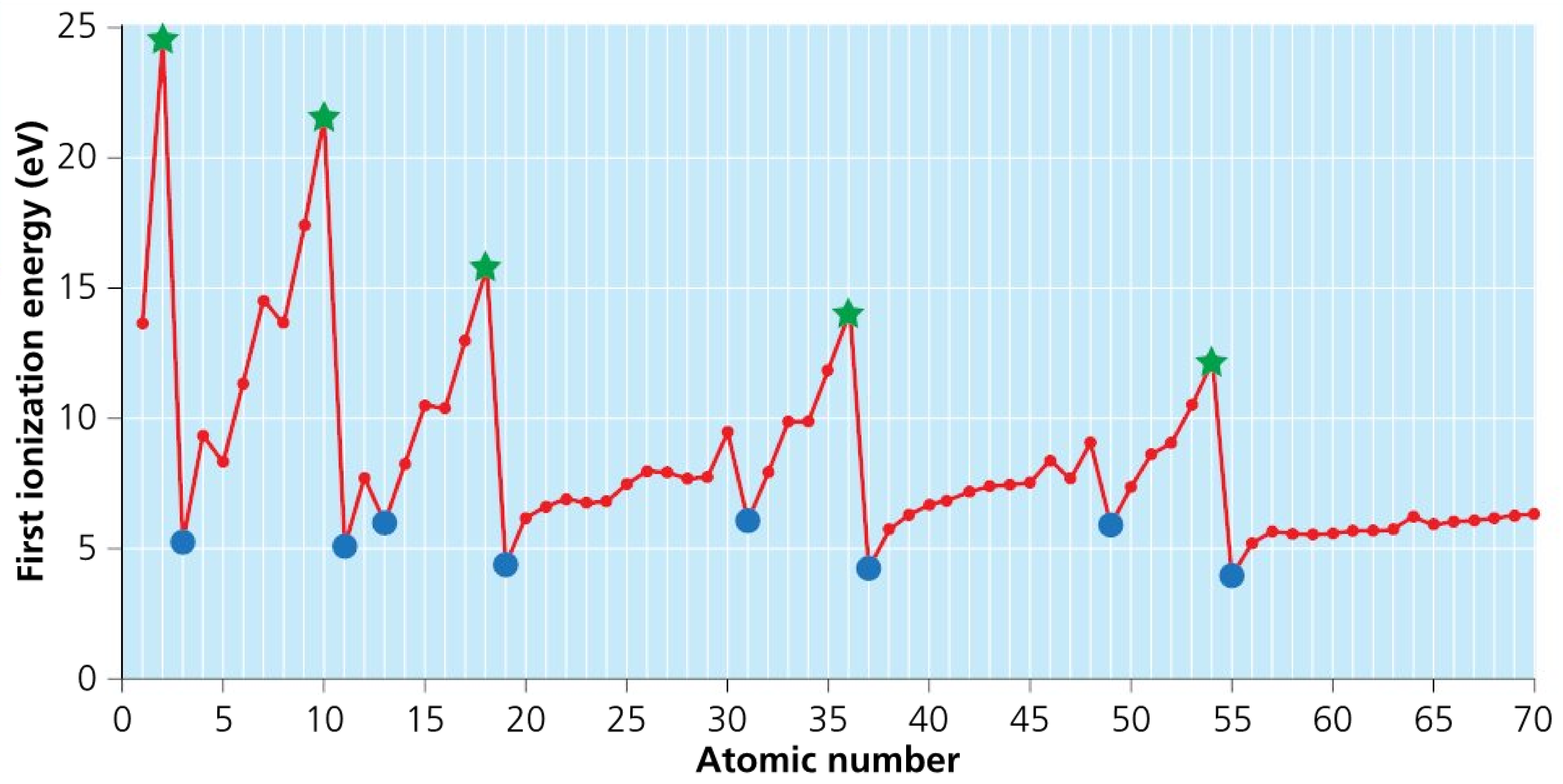
- **a** **State** how many species of animals there are in the pictures and indicate which animals belong to the same species. **Justify** your answer.
- **b** **State** which of these animals belong to the same genus. **Justify** your answer.
- **c** **Suggest** how many families of animals are represented by the animals in these pictures. Which animals belong to the same family? **Justify** your answer.

2 Using the pictures of animals from Figure 3.28:

- **a** **State** which animals' names are composed of three parts rather than the usual two in the binomial system.
- **b** **Suggest** a reason for the need to add a third part to the scientific name of the animals you mentioned in the previous question.
- **c** **Suggest** a name for the taxonomic group that comes at a lower rank than the taxonomic group of species.
- **d** **Apply** your understanding of the definition of a species to **suggest** which of these animals could mate and produce fertile offspring. **Justify** your answer.
- **e** The animal kingdom is divided into 34 phyla according to the CoL. One of these is the phylum of Chordata (known as vertebrates). Traditionally we know that vertebrates are made up of five groups (mammals, birds, reptiles, amphibians and fish). In the CoL classification, these five groups only make up five of 14 classes in the phylum of Chordata. **Suggest** which class the animals in Figure 3.28 belong to and **outline** the characteristics that you relied on in your classification.

3

- **a** Consider the following pairs: potassium and rubidium, magnesium and sulfur, argon and chlorine, oxygen and selenium. **State** which pairs will undergo similar reactions.
- **b** **Outline** why this is the case.
- **c** The element astatine (At), which sits below iodine in the periodic table, has very little currently known about it. Using your knowledge of periodic trends, **predict** some of its physical properties (state at room temperature, colour, atomic size), whether it is monatomic or diatomic and how you would expect it to react compared to the other elements in its group.
- **d** Figure 3.29 shows a graph of atomic number against first ionization energy. The ionization energy tells us how much energy is needed to remove an electron from an atom in order to form an ion with a charge of 1+. Use your periodic table to **identify** which elements are at the peaks (shown by a star) and which are at the troughs (shown by a circle) and **suggest** an explanation as to why this is the case.



■ **Figure 3.29** Graph of atomic number against first ionization energy

Reflection

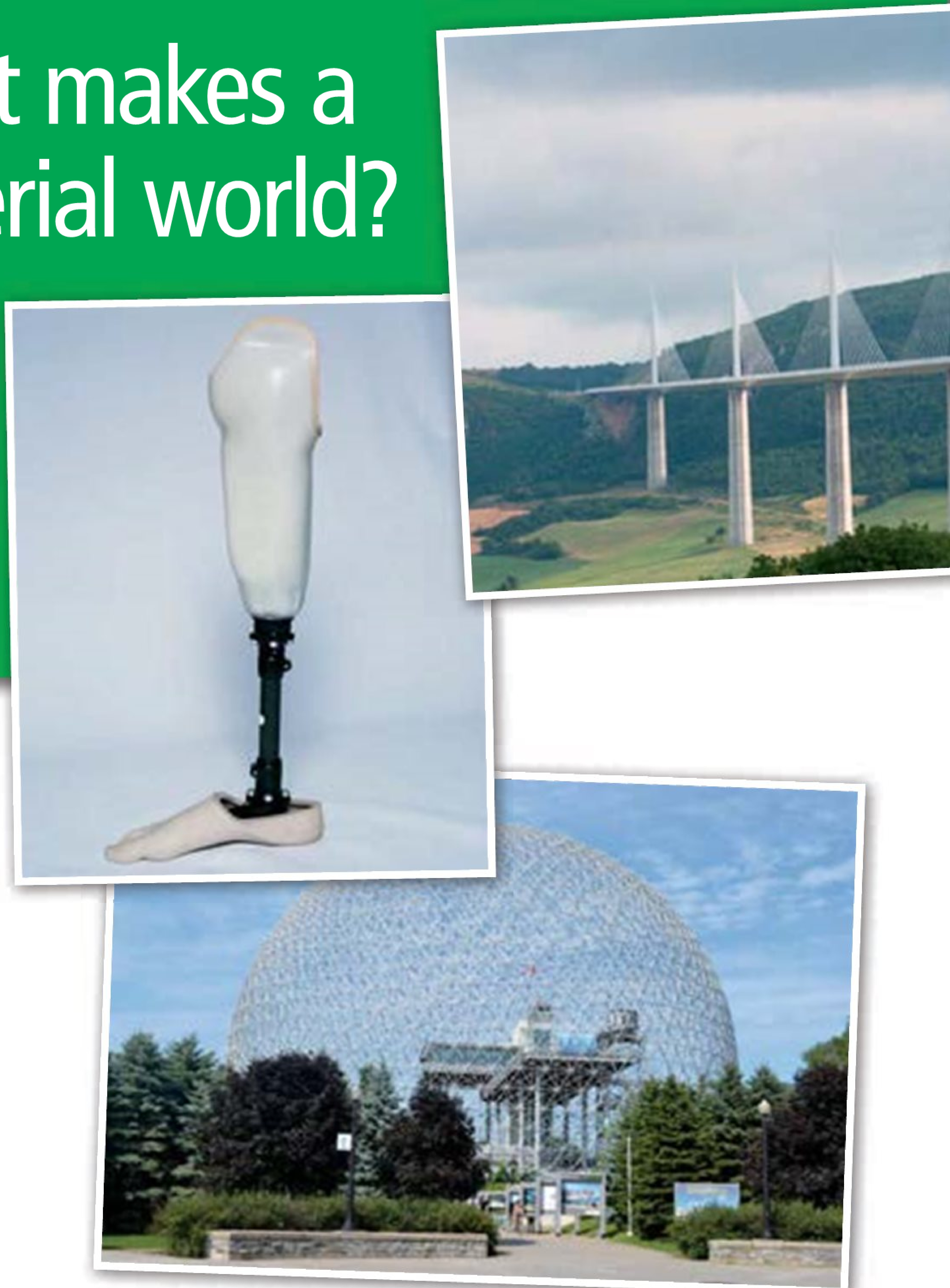
In this chapter we have explored the ways in which patterns in form can be used to identify relationships in nature, and used those relationships to invent new ways to organize and understand nature. We have **described** what the periodic table is and how each element is represented. We have **outlined** the work of different scientists who contributed to its development and **identified** trends and patterns that result from this. We have **described** the way metallic properties change across the table and **described** the main properties and uses of group 1, 17 and 18 elements. We **observed** the chemical reactions of alkali metals and halogens and used these observations and the electron arrangements of the elements to **explain** how reactivity changes going down groups. We have **defined** isotopes and ions and **explained** the relationship between the electron arrangement of an atom and the periodic table. We have **compared** the arrangement of the modern periodic table against alternative versions. Finally, we have **analysed** how living things are **classified** and **discussed** how traditional classifications have changed because of new technological advances.

Use this table to reflect on your own learning in this chapter					
Questions we asked	Answers we found	Any further questions now?			
Factual					
Conceptual					
Debatable					
Approaches to learning you used in this chapter	Description – what new skills did you learn?	How well did you master the skills?			
		Novice	Learner	Practitioner	Expert
Learner profile attribute(s)	Reflect on the importance of being a good thinker for your learning in this chapter				
Thinkers					

Change | Form; Models | Scientific and technical innovation

4 What makes a material world?

In our quest for a better life, we use existing **models** to **change** and **shape** matter into **new forms**.



■ **Figure 4.1** Structure, material and shape

CONSIDER THESE QUESTIONS:

Factual: What kinds of chemical bonds exist within living and non-living matter? How do we write word and balanced symbol equations for chemical reactions? What do forces do? How do forces work together? What is deformation?

Conceptual: How does the bonding in matter affect its physical properties? How do different structures distribute force? How does force affect materials?

Debatable: How far can we improve on natural materials?

Now **share and compare** your thoughts and ideas with your partner or with the whole class.

IN THIS CHAPTER, WE WILL …

- **Find out** how humanity has manipulated matter to make new materials and used those materials to build new structures.
- **Explore** how materials are bonded together, how forces affect them and what factors affect the design of new structures.
- **Take action** to find out how new materials and understanding of structural force can be used to design and make prosthetic limbs.

These Approaches to Learning (ATL) skills will be useful …

- Communication skills
- Organization skills
- Information literacy skills
- Critical-thinking skills
- Creative-thinking skills
- Media literacy skills
- Collaboration skills

Assessment opportunities in this chapter:

The activities in this chapter will help you develop and evaluate your learning in these MYP Sciences learning objectives:

- **Criterion A:** Knowing and understanding
- **Criterion B:** Inquiring and designing
- **Criterion C:** Processing and evaluating
- **Criterion D:** Reflecting on the impacts of science.

We will reflect on this learner profile attribute …

- Knowledgeable – knowledge of naturally occurring materials and structural force enable us to design new materials and structures.

THINK–PUZZLE–EXPLORE

You may have studied some aspects of this topic before, especially in *MYP Sciences by Concept* books 1, 2 and 3. Look at the images in Figure 4.1 and then start your learning by making notes.

- **What do you think you know about this topic?**
- **What questions or puzzles do you have?**
- **How can you explore this topic?**

At the end of the chapter, we will return to reflect on the questions you have and the answers you found.

Do you enjoy making things from new materials? Do you ever wonder how things stand up? The images in Figure 4.1 are all examples of materials in action. The structures all have a **function** and their form is designed to fulfil that function. While these objects are all quite modern, the principles behind them have been developed by human beings over many hundreds of years. Even the most modern structures conceived by designers and architects are often inspired by some of the oldest forms of all – those found in nature.

Similarly, humanity began by manipulating the natural materials we find all around us, then learnt to extract, purify and improve them, and finally to manufacture entirely new materials that are not found in nature at all.

KEY WORDS

balance	force
bond	melt
equilibrium	resultant

What kinds of chemical bonds exist within living and non-living matter?

IONIC BONDS

Chemical bonding concerns the different ways that atoms can attach themselves to each other. Bonds occur due to an atom's tendency to stability which, we saw in Chapter 3, arises when an atom has full electron shells. We see that metals, for example, on the far left of the periodic table, usually have one or two electrons in their outer shells. In their 'desire' to acquire a more stable electron arrangement, metals are quick to give up these electrons to anything that will take them. Non-metals, on the far right, have more than half-full shells so require electrons to complete their shells. The halogens in group 17 are so 'desperate' for that final electron that they will destroy anything to get it, including body cells (this is why they are known as the halogen horrors)!

So it makes sense that if a metal (that is desperate to give up its electrons) meets a non-metal (that craves electrons), they find a way to meet each other's needs. But achieving their greatest desires has consequences ... the loss of a negatively charged electron (by the metal) results in the formation of a species that has positive charge (a **cation**), while the addition of a negatively charged electron (to the non-metal) results in the formation of a species that has a negative charge (an **anion**). Opposite charges attract, so these two components are now bound for life (or until they are pulled apart by some greater force). This will be covered in more depth in Chapter 8.

An **ionic bond** is therefore an electrostatic force of attraction between oppositely charged ions that have been formed by the transfer of electrons.

We show the formation of ionic bonds through **dot-and-cross diagrams**. The steps for drawing a dot-and-cross diagram for the reaction of a metal with a non-metal are:

1. Determine the electron arrangement of the metal and non-metal involved.
2. Use the electron arrangements to draw the electron shell diagrams of the metal and non-metal.
   Use a cross to represent the electrons in one of the substances and use dots for the other. Separate these diagrams with a '+' sign.
3. Use a curly arrow to show the transfer of electrons from the metal to the non-metal. The arrow must start specifically at the electron that is leaving and end at the location it will occupy on the shell of the non-metal. If more than one electron moves, use additional arrows.
4. Draw the new electron shell diagram of the metal and non-metal, using crosses and dots as previously.
5. Place each individual ion formed in square brackets. This indicates that it is an ion. Write the charge in the top right-hand corner (the number comes before the sign).
6. Write the new electron arrangement of the metal and non-metal. These will now be noble-gas configurations, as both the metal and non-metal will have full shells.
7. Try to write the name and formula of the product (covered later on in Chapter 4).

ACTIVITY: My name is Bond, Ionic Bond – taken, not shared

ATL

- Communication skills: Use and interpret a range of discipline-specific terms and symbols; Understand and use mathematical notation
- Information literacy skills: Present information in a variety of formats and platforms; Understand and use technology systems

1. **Formulate dot-and-cross diagrams for the following reactions that lead to the formation of ionic compounds:**
   a. **sodium and chlorine**
   b. **calcium and fluorine**
   c. **beryllium and sulfur**
   d. **potassium and oxygen**
   e. **magnesium and nitrogen.**
2. **Deduce the name and suggest a formula for each ionic compound.**

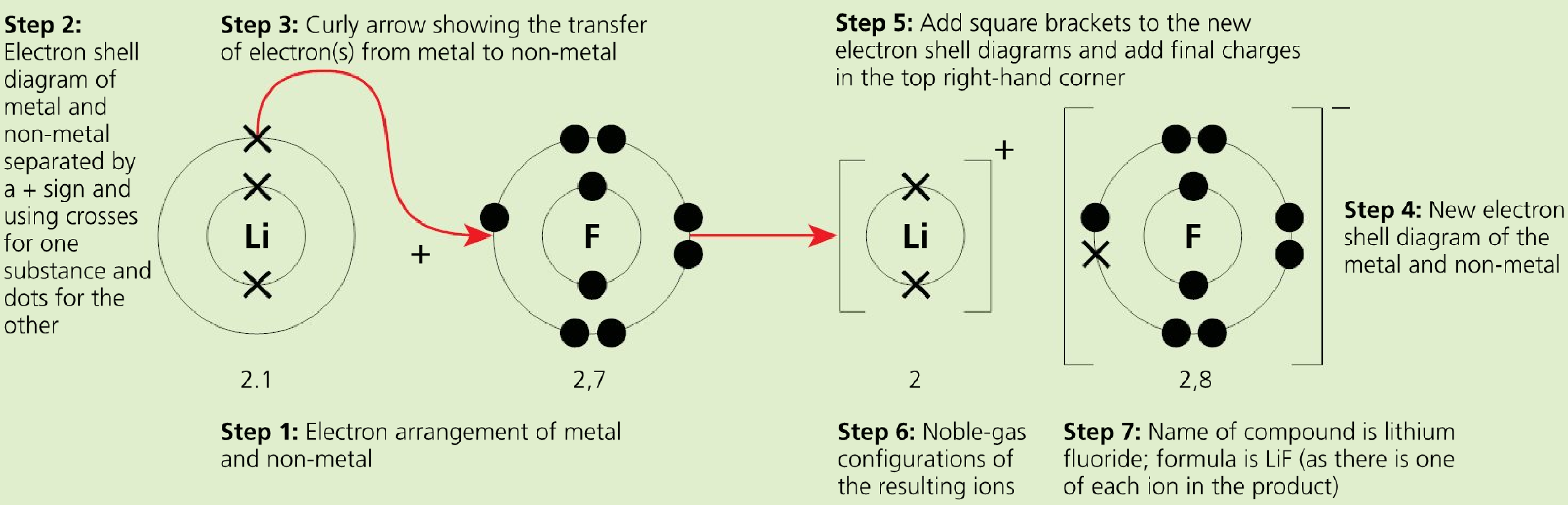
Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

Worked example

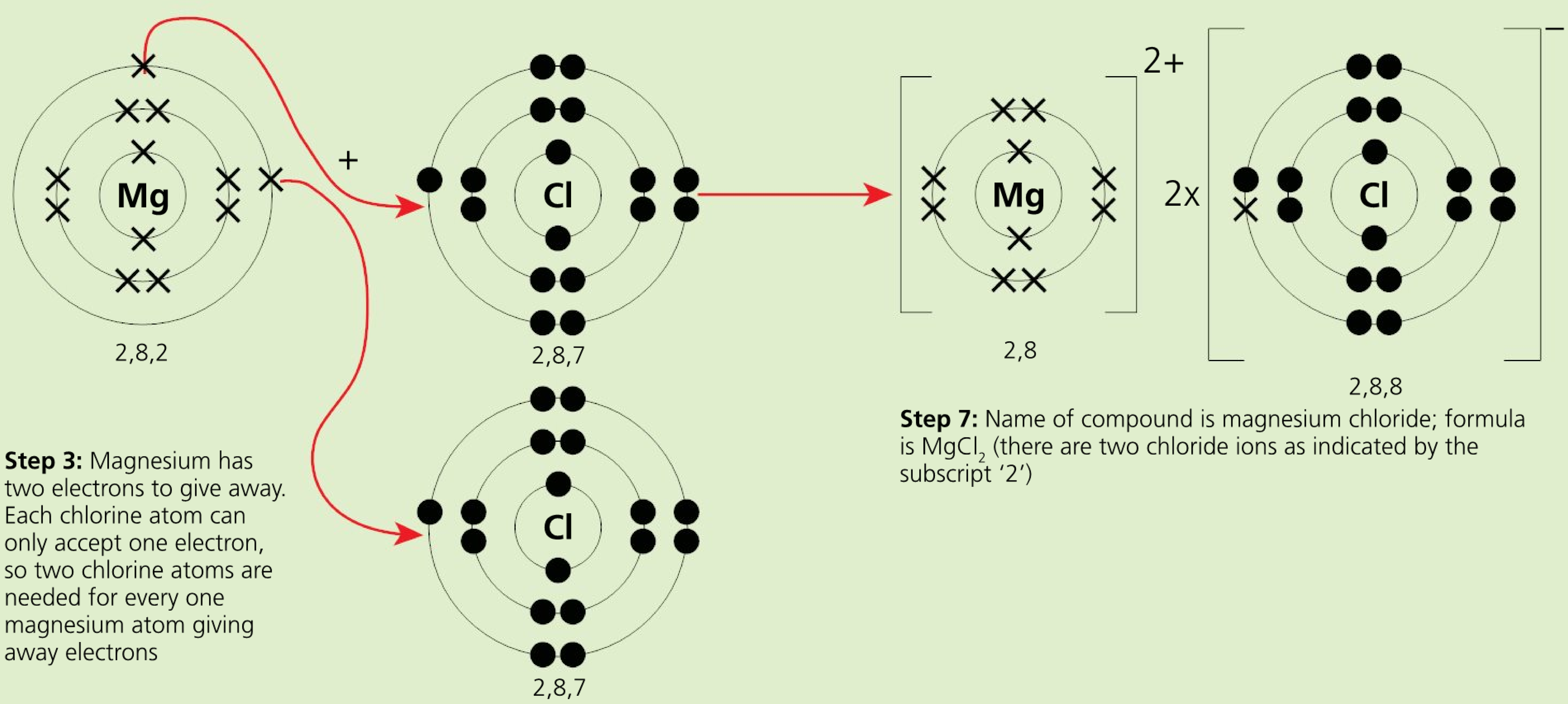
Here we see how to show the formation of the ions that are held together by ionic bonds, using dot-and-cross diagrams.

Example: Lithium and fluorine

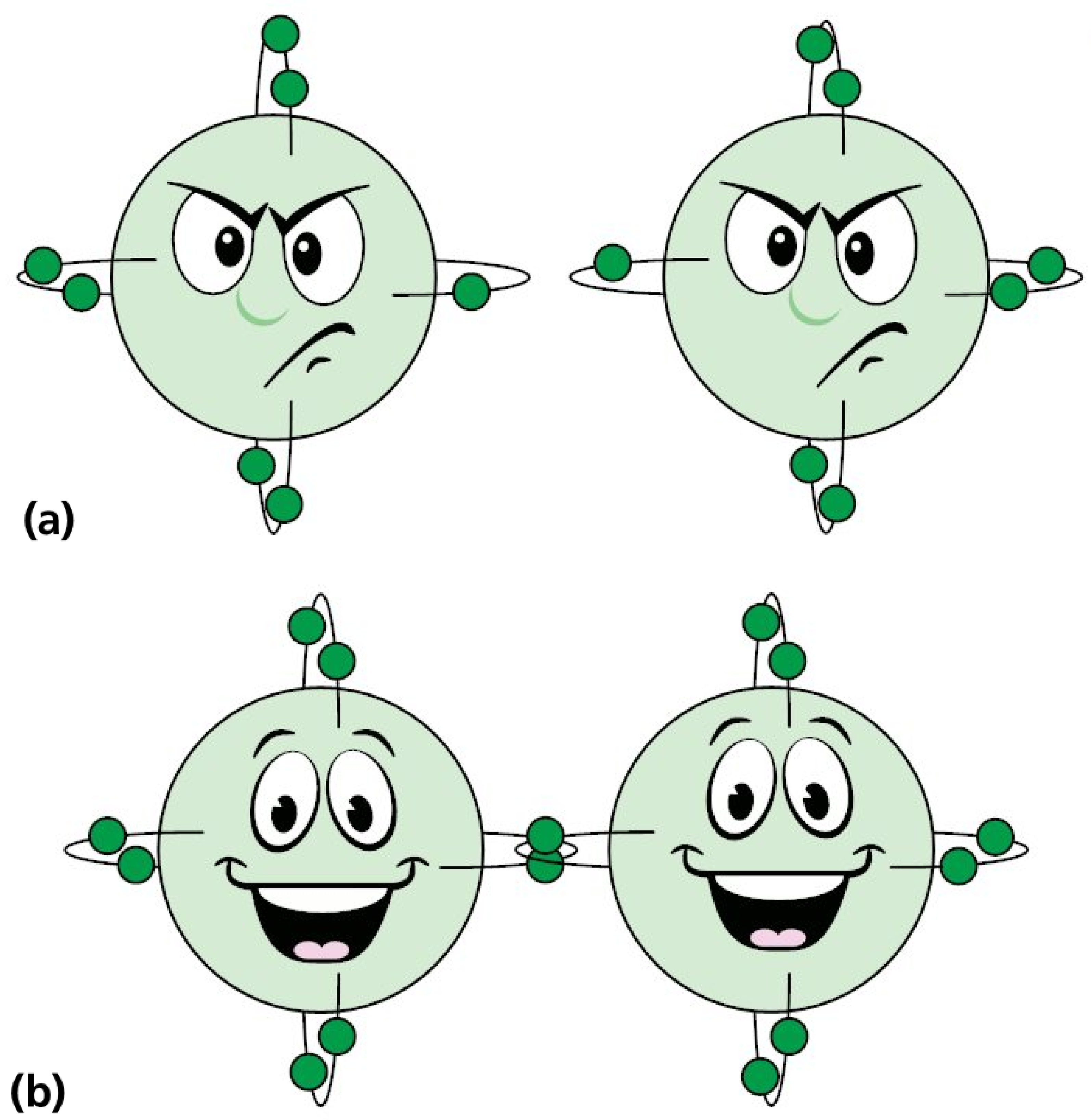


■ **Figure 4.2** Dot-and-cross diagram for the reaction of lithium and fluorine

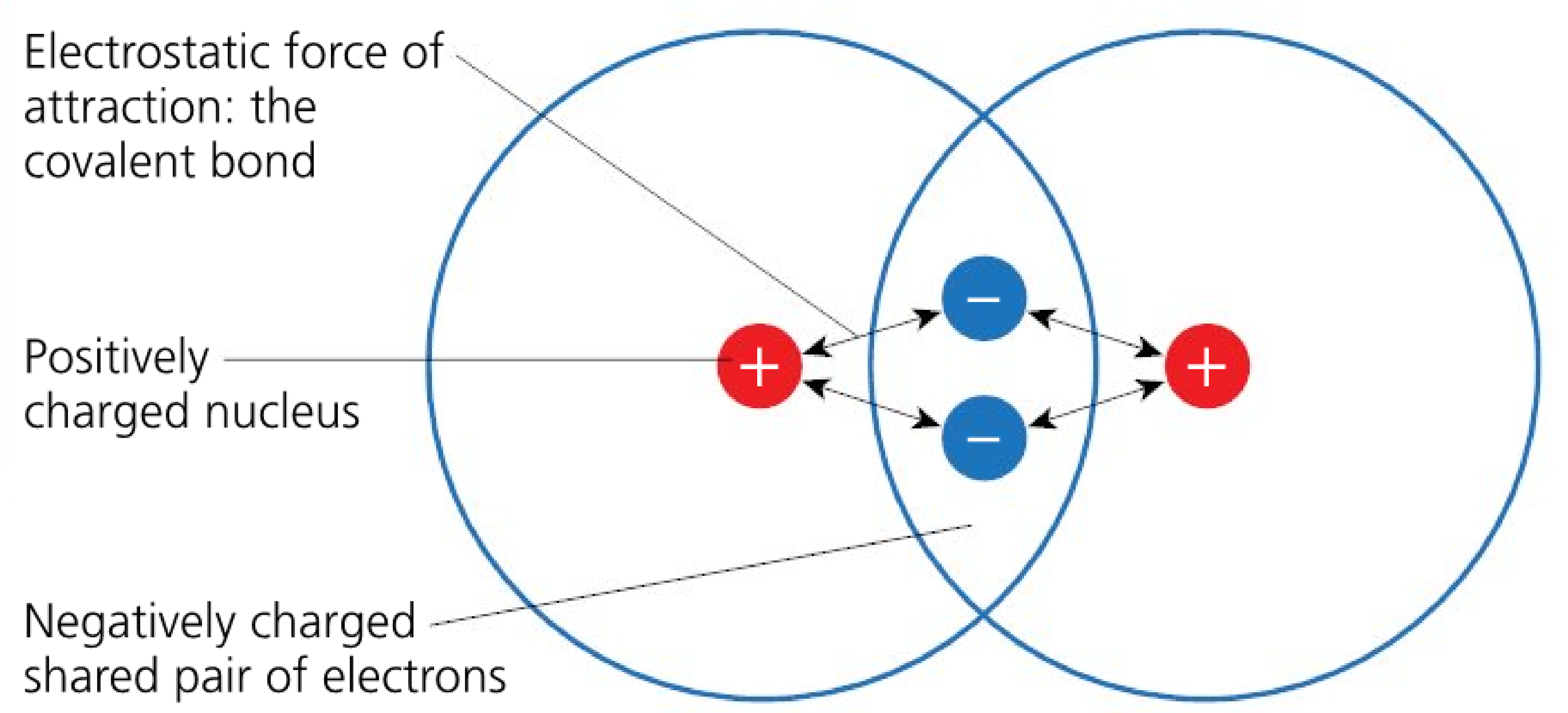
Complex: Magnesium and chlorine



■ **Figure 4.3** Dot-and-cross diagram for the reaction of magnesium and chlorine



■ **Figure 4.4** (a) The two chlorine atoms are both missing an electron. (b) They reach a compromise, each sharing an electron to complete their octets.



■ **Figure 4.5** The electrostatic force of attraction in a covalent bond exists between the positively charged nuclei and the negatively charged shared pair of electrons

COVALENT BONDS

Ok, so what about two non-metals? Let's imagine there are two individual chlorine atoms darting around, aggressively looking for that final electron to complete their shells. They spot each other and approach with care, knowing full well the carnage that the other atom is capable of causing. Is it a case of the winner takes it all or can they collaborate and find a compromise? They strike a deal … each chlorine atom shares one of their electrons with the other, so both manage to complete their octets.

Covalent bonds are formed when electrons are shared (mnemonic: Sharing is **C**aring). So where does the electrostatic force of attraction come from? For an electrostatic force to exist, there must be opposite charges. In the case of the covalent bond, the positive charge comes from the nucleus, while the negative charge comes from the shared pair of electrons.

A covalent bond can therefore be defined as an electrostatic force of attraction between the positively charged nuclei and the negatively charged shared electrons.

We show the formation of covalent bonds using **Lewis symbols** for the elements involved and **Lewis (electron dot) structures** for the products formed. Lewis symbols are a modification of the electron shell diagrams you met in Chapter 2, in that they only include the outer shell, or valence, electrons. Lewis structures show the final compound and include the covalent bond(s) formed.

The steps for drawing a dot-and-cross diagram for the reaction of two non-metals are:

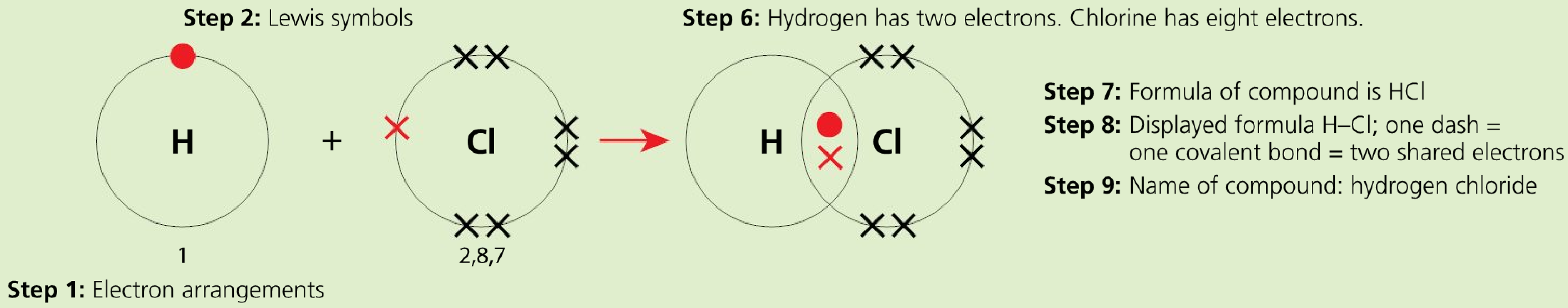
1. Determine the electron arrangement of the non-metals involved.
2. Use the electron arrangement to draw their Lewis symbols. Use a cross to represent the electrons in one of the substances and use dots for the other. Separate these diagrams with a '+' sign.
3. Draw the Lewis structure of the product. To do this, first draw the valence shells of the two elements, shown as two overlapping circles on the product side with the symbols of the elements in the centre of each circle.
4. The unpaired electrons are the ones that need to be shared. Place the unpaired electrons in the centre of the two overlapping circles.
5. Place the remaining paired electrons on the shells of the relevant atoms, keeping them in pairs.
6. Count the valence electrons around each atom. The shared electrons are included for both atoms. There should be eight (or two if one of the elements is hydrogen).
7. Write down the formula of the product.
8. Draw the displayed formula of the product (the element symbols and any covalent bonds, pairs of electrons, shown with a dash).
9. Try to write down the name of the product.

Any substance that is made up of covalently bonded atoms is called a molecule. Molecules can be elements, where both atoms are the same like oxygen, or compounds which are made of two or more different atoms chemically combined, like hydrogen chloride.

Worked example

Here we see how to show the sharing of electrons in a covalent bond, using Lewis symbols and Lewis structures.

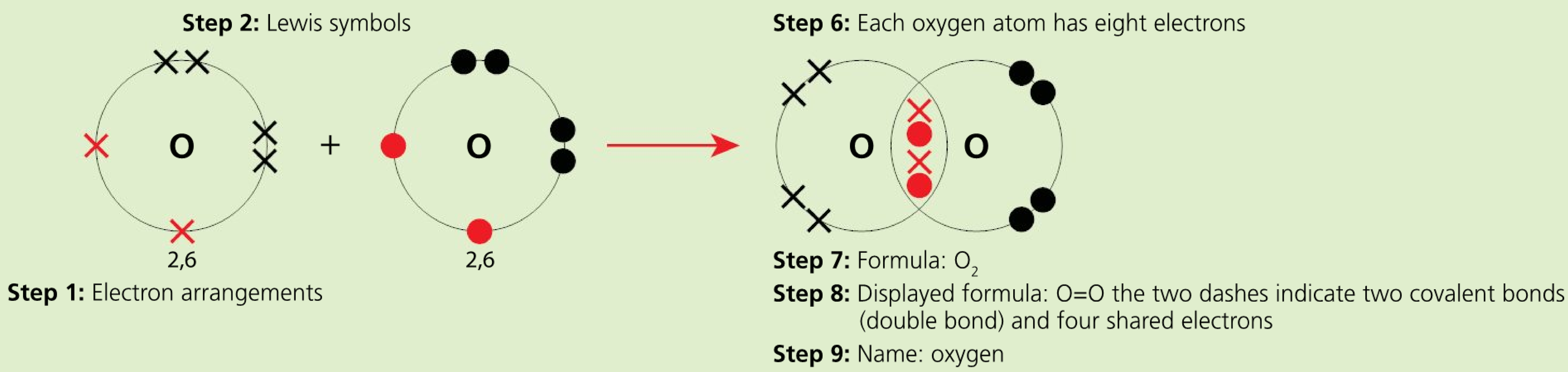
Example: The reaction of a hydrogen atom and a chlorine atom



■ **Figure 4.6** Lewis structure for hydrogen chloride

The pairs of electrons that are not involved in bonding are called **lone pairs**.
The chlorine atom has three lone pairs of electrons.

Challenging: Oxygen



■ **Figure 4.7** Lewis structure for oxygen

ACTIVITY: 'Didn't anyone ever teach you to share?'

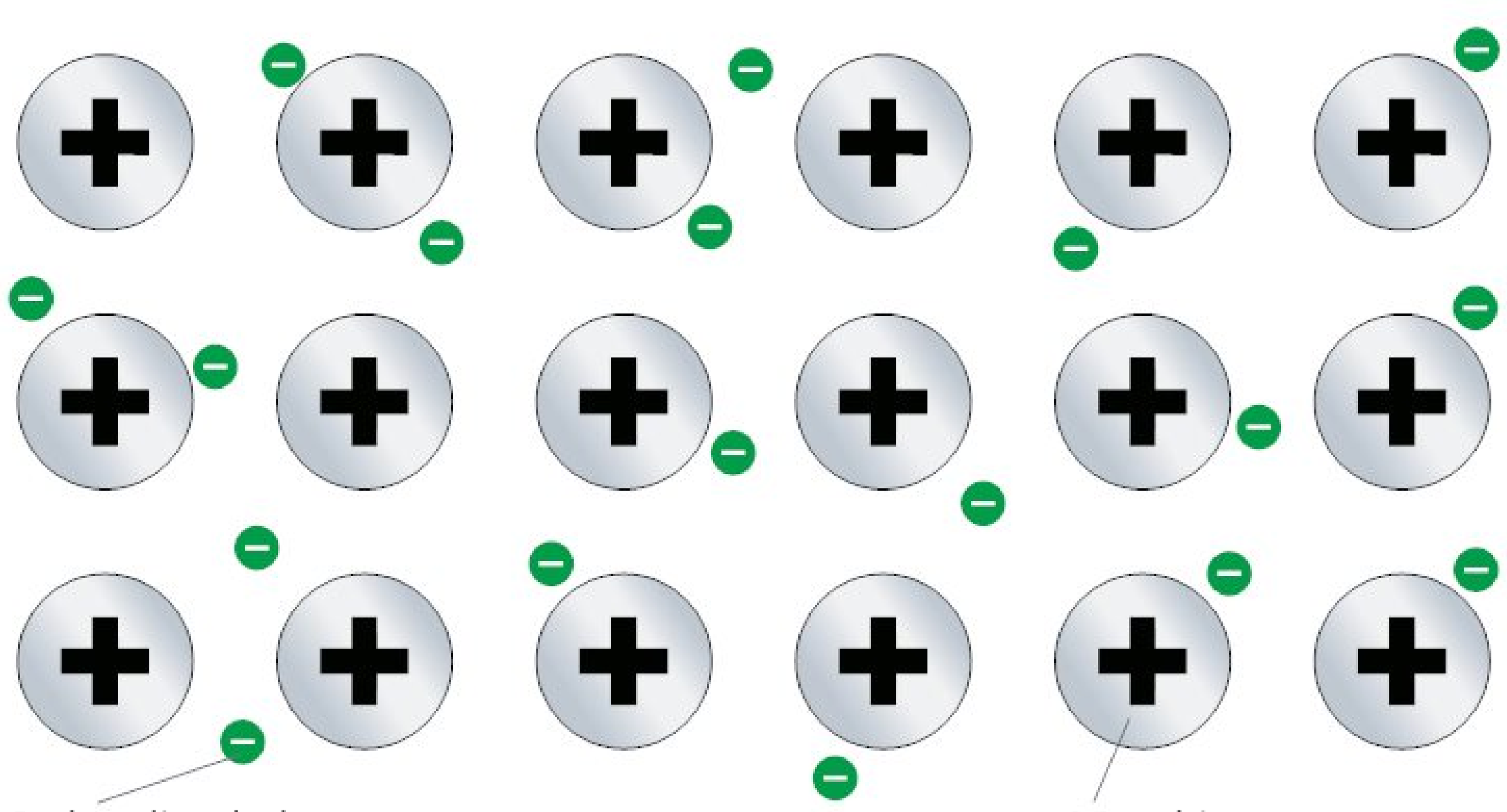
ATL

- Communication skills: Use and interpret a range of discipline-specific terms and symbols; Understand and use mathematical notation
- Information literacy skills: Present information in a variety of formats and platforms; Understand and use technology systems

1 **Construct** Lewis symbols for the following elements:
   a hydrogen
   b fluorine
   c chlorine
   d oxygen
   e nitrogen
   f carbon.
2 Use the Lewis symbols to **construct** Lewis structures for the following covalent molecules:
   a the bonding between hydrogen and fluorine atoms
   b fluorine gas
   c chlorine gas
   d the bonding between hydrogen and oxygen atoms
   e the bonding between nitrogen and hydrogen atoms
   f nitrogen gas
   g ethane (C_2H_6)
   h methanol (CH_3OH).
3 **Deduce** the formula of each substance in Question 2 and **suggest** the displayed formula and the name (where relevant).

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.



■ **Figure 4.8** Metallic bonds are the electrostatic force of attraction between the positive ions (formed after delocalizing their valence electrons) and the electron cloud

METALLIC BONDS

The final type of bond we are going to focus on is metallic bonding. This form of bond helps us to explain the properties of metallic substances. **Metallic bonds** exist within metals. Even the tiniest piece of metal consists of billions of atoms. Most metals exist in the solid state at SATP (25 °C and 100 kPa), which means that the atoms are arranged in a regular **lattice**, are very close together and vibrate about their positions (Figure 4.8). These atoms also have very strong forces of attraction between them; in the case of metals, these forces of attraction are the metallic bonds.

So what causes the bond or electrostatic force of attraction? Metals have few electrons in their outer shells so each atom can donate or 'delocalize' its valence electrons. If the metal is in group 1, each atom will delocalize one electron; if the metal is in group 2, each atom will delocalize two electrons. These delocalized electrons form a 'sea of electrons' that is constantly moving through the lattice. By delocalizing their valence electrons, the atoms have now become ions. Metallic bonds, therefore, are the electrostatic force of attraction between the positively charged ions and the negatively charged delocalized electron cloud.

The electrons in the delocalized electron cloud do not form specific bonds with specific ions. As the cloud is moving constantly through the lattice, these bonds are being broken and re-made continuously; a feature that explains some of the key properties of metals.

> **DISCUSS**
>
> In Chapter 3, you met some of the common properties of metals. Which of those do you think are related to the bonding in metals?

NAMING COMPOUNDS

We know that when different atoms combine ionically or covalently, new substances are formed. So how do we name these products? In this section you will find clear rules that will enable you to name ionic and covalent compounds.

There are some exceptions where covalent compounds are not named according to these rules: water (H_2O), ammonia (NH_3) and organic compounds like methane (CH_4) are just some examples. Compounds that consist of the elements carbon and hydrogen are called **hydrocarbons**; they are part of a wider group of organic compounds and have their own nomenclature (see Chapter 5).

How to name ionic and covalent compounds

1 Naming ionic compounds which consist of a metal (excluding transition metals) and a non-metal.
- The name of the metal comes first and stays the same.
- The name of the non-metal comes second and takes on the special suffix (ending) of 'ide'.

For example, when sodium metal is exposed to air, it reacts with the oxygen in the air (Chapter 3). Sodium is a metal, while oxygen is a non-metal so the product will be an ionic compound and its name will be sodium oxide (Na_2O).

While the reactants comprise neutral sodium atoms and neutral oxygen molecules, the product (the ionic compound) is made of sodium and oxygen ions.

2 Naming ionic compounds which consist of a transition metal and a non-metal.

Transition metals are different to the main group metals because they can have variable charges/chemical forms.
- The name of the metal comes first and stays the same.
- The charge of the metal/chemical form is indicated as a roman numeral in brackets after the name of the metal. The exception is for zinc, which only has one charge/chemical form.
- The name of the non-metal comes next and takes on the special suffix (ending) of 'ide'.

For example ionic compounds of copper and oxygen include copper (I) oxide (Cu_2O) or copper (II) oxide (CuO). Note that the ionic compounds of transition metals are not necessarily formed by the direct combination of the transition metal and non-metal.

3 Naming covalent compounds which consist of two different non-metals.
- Write down the names of the elements, with the one furthest to the left of the periodic table first.
  - The exceptions are chlorine, bromine and iodine which come before oxygen (this is based on the relative attraction that an atom has for the shared pair of electrons in a covalent bond but we don't cover electronegativity at this level).
- Change the end of the name of the element that comes second to 'ide'.
- If there is more than one of any of the types of atoms, the name will take on a special prefix to indicate how many atoms are present.
  - Mono = 1 (the final 'o' is often dropped to make the pronunciation easier)
  - Di = 2
  - Tri = 3
  - Tetra = 4 (the final 'a' is often dropped to make the pronunciation easier)
  - Penta = 5 (the final 'a' is often dropped to make the pronunciation easier)
    - Exception – no prefix is necessary if there is only one of that type of atom.
    - Exception – no prefix is added to the front of hydrogen.
- If oxygen is present, the oxide also takes one of these special prefixes that indicate how many oxygen atoms there are; for oxygen this is the case even if there is only one oxygen atom present. For example:
  - CO_2 is carbon dioxide (carbon comes first as it is furthest to the left, no prefix for the carbon as there is only one atom present; oxygen becomes oxide and has a prefix, di- as there are two present)
  - Br_2O_3 is dibromine trioxide (bromine comes first even though it is to the right of oxygen; there are two bromine atoms so it takes on a prefix, di-; oxygen becomes oxide and has a prefix, tri- as there are three present)
  - HCl is hydrogen chloride (hydrogen comes first as it is furthest to the left; no prefix for the hydrogen; chlorine becomes chloride but does not require a prefix as there is only one).

ACTIVITY: Naming compounds

ATL

- Communication skills: Use and interpret a range of discipline-specific terms and symbols; Understand and use mathematical notation
- Information literacy skills: Present information in a variety of formats and platforms; Understand and use technology systems

Copy and complete Table 4.1 by working out the name of the compound for each of the formulae given.

Assessment opportunities

- In this activity you have practised skills that can be assessed using Criterion A: Knowing and understanding.

Formula	Name of compound	Formula	Name of compound
CaO		Br_2O	
AgCl (silver charge 1+)		H_2S	
Ca_3P_2		NO_2	
$SnCl_4$ (tin charge 4+)		SO_3	
MgS		N_2O_4	
NaN_3		BrO_2	

Table 4.1 Deducing the names of ionic and covalent compounds

How does the bonding in matter affect its physical properties?




■ **Figure 4.9** Different types of bonds result in different properties

SEE–THINK–WONDER

Look at the images in Figure 4.9. What do you **see**? What do they make you **think** about? What do they make you **wonder**?

EXPLANATION GAME

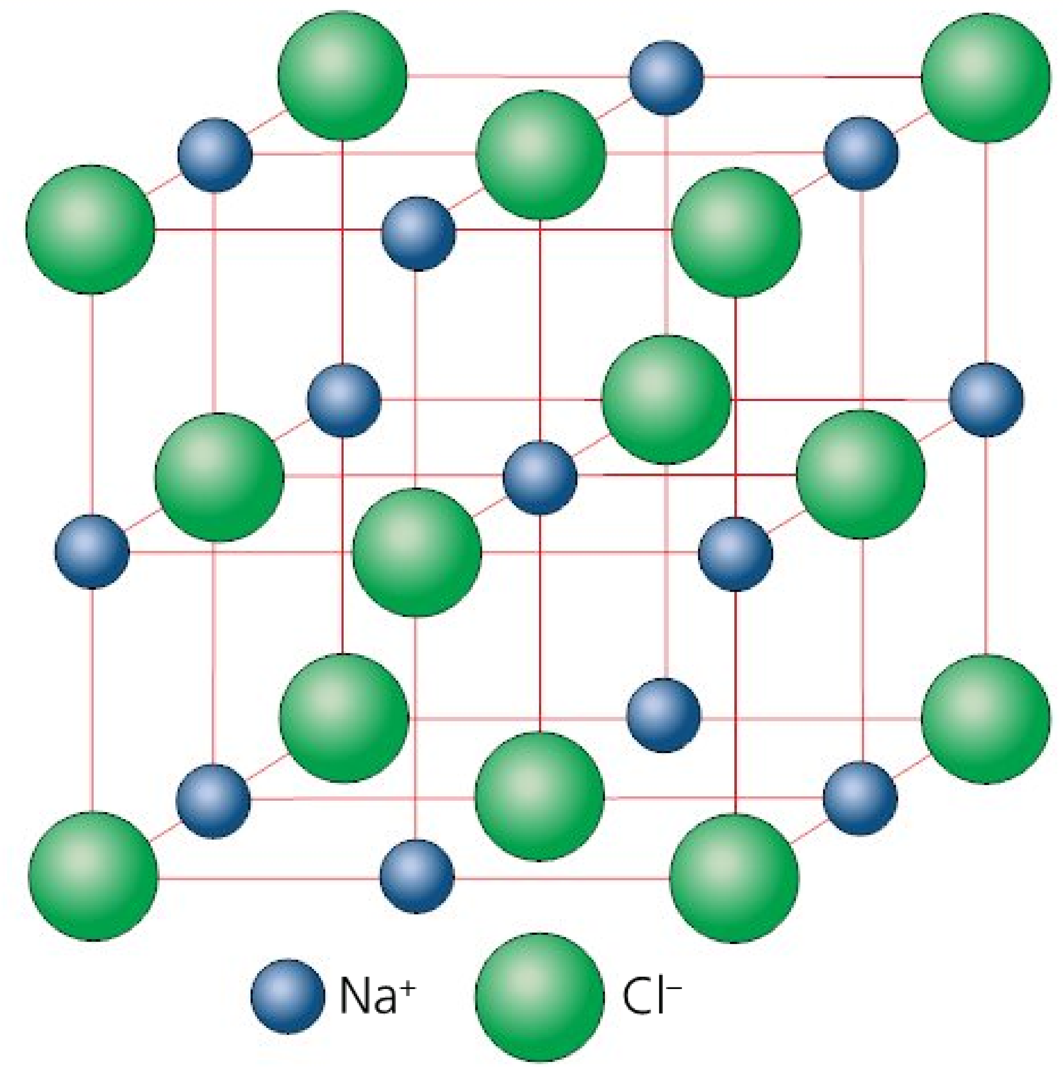
The images in Figure 4.9 show some of the key properties of different substances. These properties depend on the type of bonding present. Why is sodium chloride, common salt, a crystal? Why is it soluble in water? Why is diamond one of the hardest known substances? Why are metals so good at bending into such different shapes and conducting electricity?

Can you match these properties with their explanations?

I notice that …	Why is it that way?
The substance exists as a crystal.	There are free-flowing charged particles.
The substance is extremely hard.	Layers of atoms can slide over each other without disrupting the bonding.
The substance is malleable and ductile.	The atoms/ions are held together by strong electrostatic forces of attraction that have to be broken.
The substance has a very high melting point.	The ions are arranged in a lattice structure. This regular arrangement leads to the formation of a crystal.
The substance conducts electricity.	Strong electrostatic forces of attraction draw the atoms/ions close together.

IONIC COMPOUNDS

An ionic bond is formed when oppositely charged ions (that are formed as a result of the transfer of electrons) attract. But a cation will not attract a single anion; it will attract anions from all directions so that it ends up being surrounded by them, attracted to each by an ionic bond. In turn, each of those anions will be attracted to a number of cations. The result? An ionic lattice with a regular arrangement of billions of ions, where each ion is surrounded by ions of the opposite charge and the whole structure is held together by ionic bonds. Figure 4.10 shows how sodium and chloride ions arrange themselves in the ionic lattice of sodium chloride. Each ion is surrounded by six



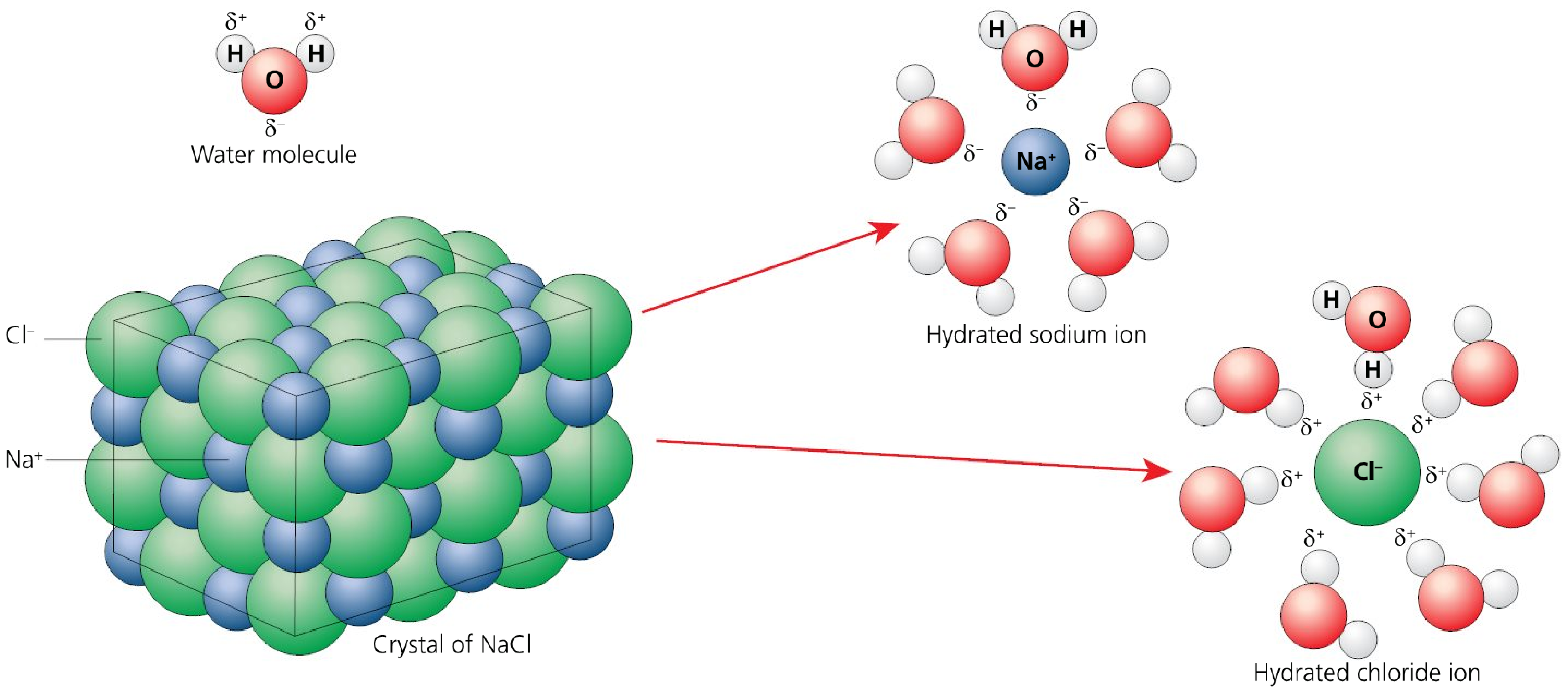
■ **Figure 4.10** The ionic lattice of common table salt, sodium chloride (NaCl)

of the opposite charge (you can see this if you look at the very central ion). Depending on the size of the ions in the compound, there will be different arrangements, which in turn will have an effect on the shape of the crystal formed.

When you heat up an ionic compound, you need to break the strong ionic bonds in the lattice to cause the substance to melt. This requires a significant amount of energy, which is why ionic compounds have extremely high melting points. Further, the strong electrostatic forces of attraction (ionic bonds) pull the ions very closely together, which is why most ionic compounds are hard. This also makes them brittle; pushing the ions will result in ions of the same charge being next to each other, causing repulsions which break the layers apart.

Ionic compounds are soluble in water. This is because water molecules are able to disrupt the ionic lattice. The partially positive parts of the water molecules (the hydrogen atoms) surround the anion of the ionic compound, while the partially negative parts (the oxygen atoms) surround the cation, pulling them apart and forming hydrated ions.

Ionic compounds in the solid state do not conduct electricity. This is because the ions are held in fixed positions, so while they are charged, they are unable to flow and therefore carry electric charge. However ionic compounds can conduct electricity in the molten state or in solution. This is because the charged ions are now free to move.



■ **Figure 4.11** What happens to sodium chloride in water? The anions (chloride ions) and cations (sodium ions) are pulled apart and become surrounded by different parts of the water molecules.

EXPLANATION GAME

Make a list of some covalent substances that you are familiar with.

Hint

Diatomic elements are covalent.

What do you notice about the physical state that most of these are in at SATP? Why is it that way?

COVALENT COMPOUNDS

The physical state of matter gives an indication of the strength of the bonds between the particles that need to be broken for a change of state to occur. When simple covalent molecules change state, it isn't the strong covalent bonds that break. Think of a cup of water that consists of water molecules in the liquid state. If you heat that water in a pan, you form a vapour. That vapour still consists of the same water molecules, which means that the covalent bonds between the oxygen and hydrogen atoms have remained intact. So what bonds have broken?

When simple covalent molecules change state, it is the weaker **intermolecular forces** that are broken. Intermolecular forces are bonds between molecules. There are three types – **London forces**, dipole–dipole forces and hydrogen bonds. Being weaker types of bonds, these require less energy to be broken, resulting in lower melting and boiling points. For this reason, most simple covalent molecules exist in the gaseous state at SATP.

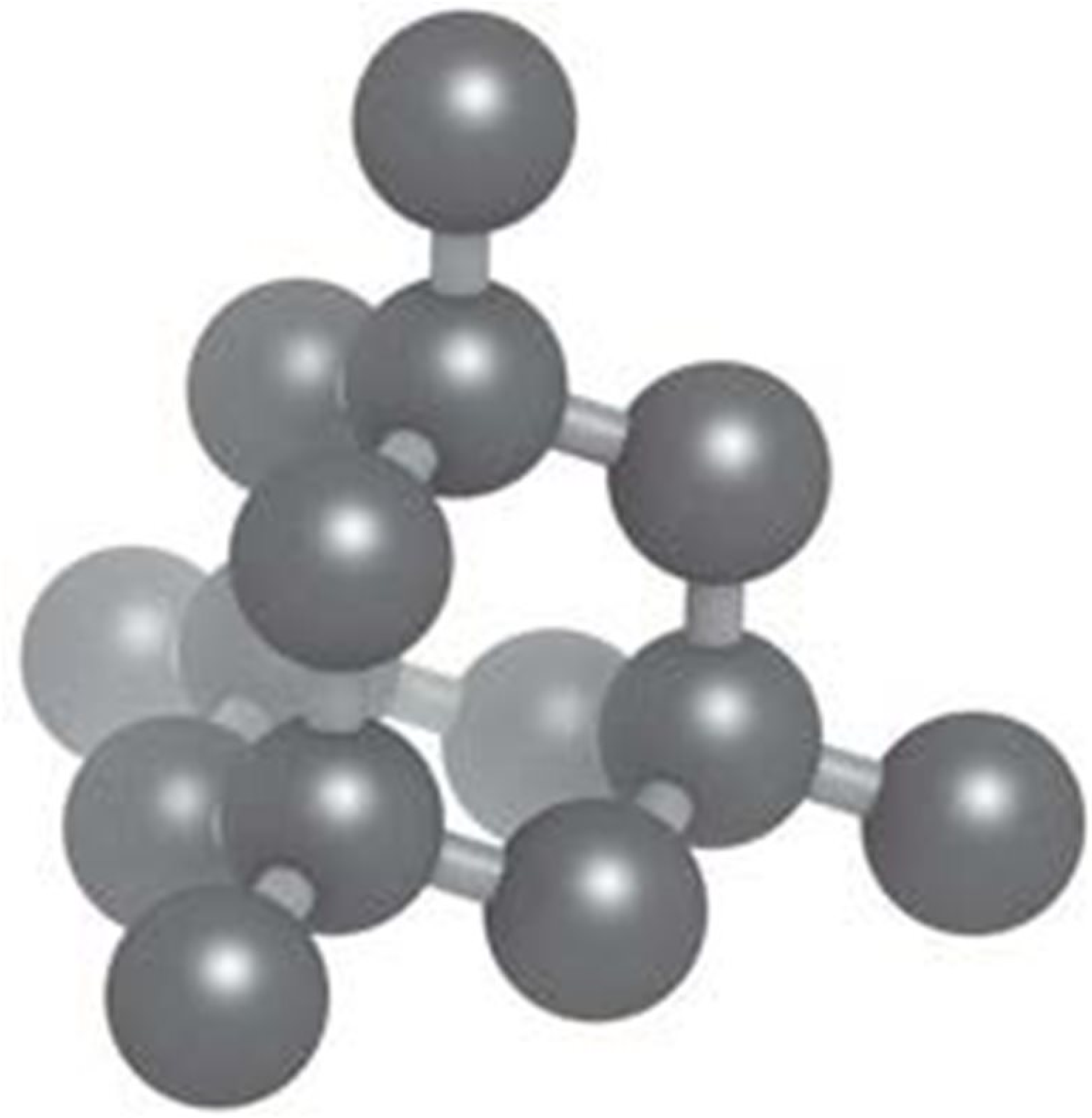


Figure 4.13 The tetrahedral 3D arrangement of carbon atoms in diamond

Carbon is a very special element because of its ability to bond in the way that it does. Carbon is in group 14 of the periodic table, which means it has four outer shell electrons, each of which is capable of being shared in a covalent bond. Carbon atoms covalently bond to other non-metals, but they can also covalently bond to themselves. This means they can continue to join up, leading to the formation of a huge diversity of long-chain molecules which can also become quite complex and contain branches. **Organic chemistry** is all about these carbon-based molecules and is particularly important in understanding the chemistry of amino acids, proteins and DNA, the building blocks of human beings.

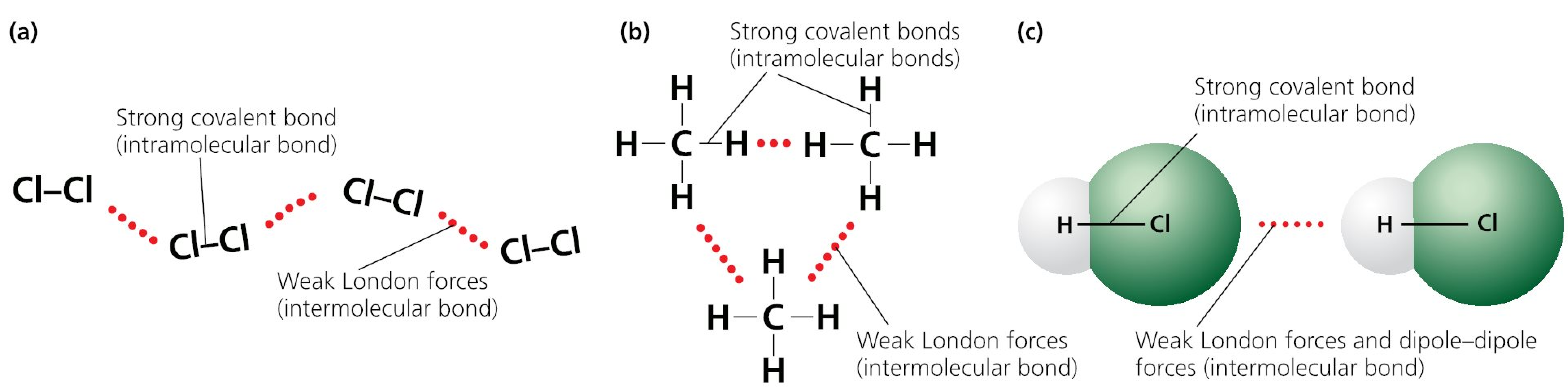


Figure 4.12 The weak London forces between (a) chlorine molecules and (b) methane molecules means they exist as gases at SATP. (c) Hydrogen chloride has London forces and dipole–dipole forces, but still exists as a gas at SATP.

Carbon is special in another way. When it bonds to itself it is able to arrange its atoms in different ways, resulting in structures with vastly different properties. Both dazzling diamonds and grey-black graphite are made of elemental carbon, with a very different arrangement of its atoms.

In diamond, each carbon atom is covalently bonded to *four* other carbon atoms. These carbon atoms spread themselves as far away from each other as possible, resulting in a tetrahedral shape.

This arrangement gives diamond its properties.

- Diamond has an extremely high sublimation point. This is because the strong covalent bonds have to be broken throughout the whole structure before it can sublime.
- Diamond is extremely hard, therefore often used in drills. This is because the strong covalent bonds form a cage-like structure with interlocking hexagons throughout the structure and have to be broken to separate the atoms.
- Diamond does not conduct electricity. This is because all of the electrons are involved in bonding and none are free to move and carry charge.

In graphite, each carbon atom is covalently bonded to *three* other carbon atoms. The atoms spread out from each other as much as possible so they are at 120° angles. The result is that the carbon atoms form connected hexagons. The hexagons are arranged in 2D layers that are held together by weak London forces.

This arrangement gives graphite its properties.

- Graphite also has an extremely high sublimation point. This is because the strong covalent bonds have to be broken before it can sublime.
- Graphite is soft and slippery. This is because the weak London forces allow the layers to slide over each other.
- Graphite is a conductor of electricity. This is because each carbon atom has one electron that is not involved in bonding. These electrons are free to move between the layers and carry charge.

Diamond and graphite are known as **allotropes** of carbon. Both substances have a covalent network structure, so are called covalent network solids.

The miracle of carbon does not end with diamond and graphite. The new field of nanotechnology (briefly mentioned in Chapter 2) centres around the discovery of two other carbon allotropes: **fullerenes** and **graphene**.

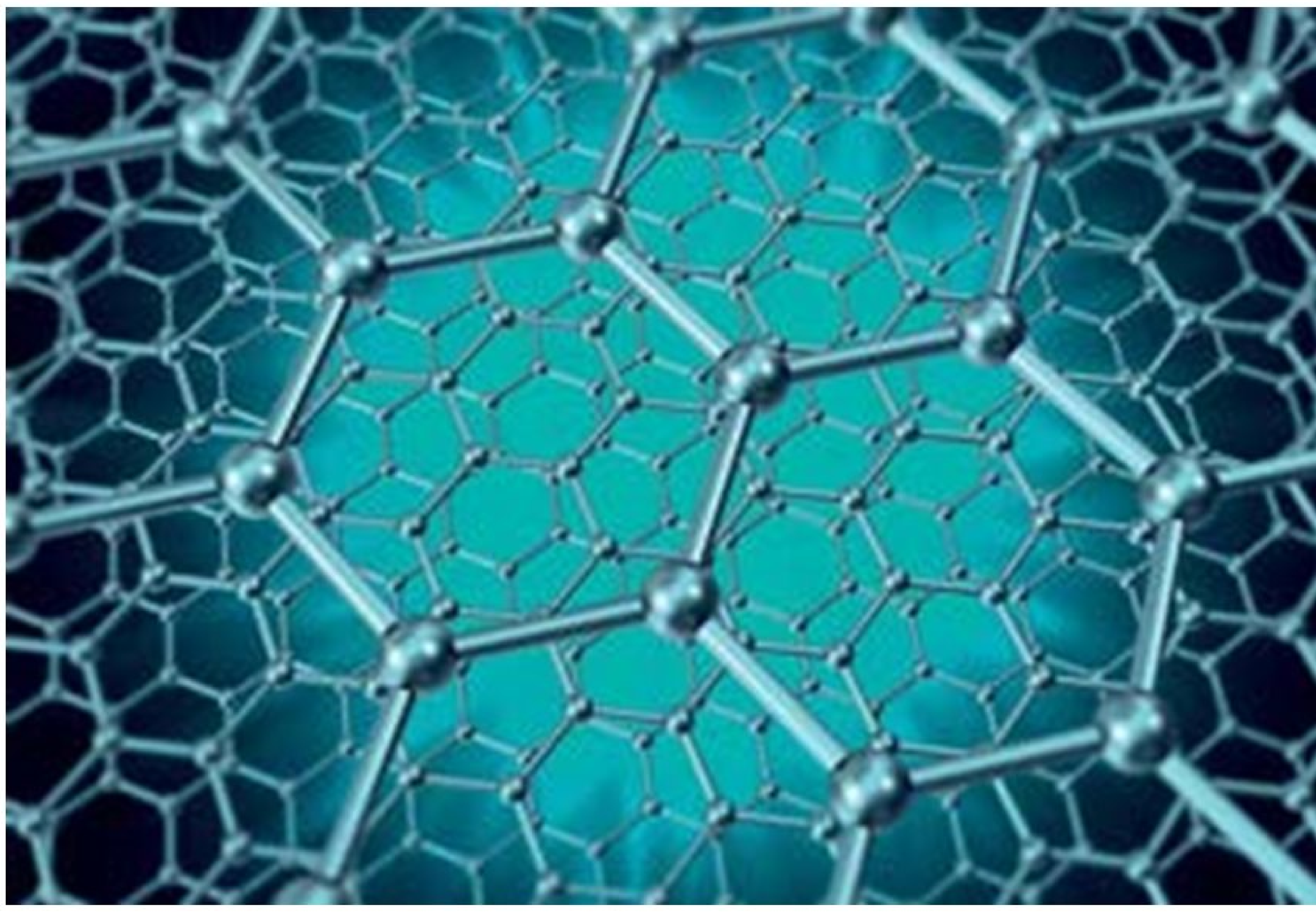


Figure 4.14 The connected hexagons of carbon atoms, arranged at 120° angles in graphite. The hexagons form layers that are held together by weak London forces.

EXPLANATION GAME

Metals:

- usually have high melting and boiling points
- are usually hard and dense
- conduct electricity
- are malleable and ductile.

Why is this the case?

ACTIVITY: Graphene

ATL

- Communication skills: Preview and skim texts to build understanding; Paraphrase accurately and concisely; Take effective notes in class
- Media literacy skills: Locate, organize, analyse, evaluate, synthesize and ethically use information from a variety of sources and media (including digital social media and online networks)

The University of Manchester, in the UK, has a website dedicated to graphene, covering everything from its discovery there in 2004, to its properties, to the latest papers on its potential uses:
www.graphene.manchester.ac.uk/

Your task is to find out more about this super-material, starting your research at the University of Manchester's website.

The aim of your research is to be able to complete the following tasks:

- **Outline what graphene is.**
- **Describe how it was finally isolated (there have been attempts to study it since 1859).**
- **Identify some of the properties of graphene.**
- **Describe some of the products that graphene could be used in and what property that use relies on.**
- **Outline any problems with using graphene.**

Use the information you have found and the answers to the tasks above to **evaluate** the statement that graphene is 'the material of the future'.

The university's website has a number of other videos to watch as well as a webpage dedicated to the potential applications of graphene.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding and Criterion D: Reflecting on the impacts of science.

METALS IN PARTNERSHIP

The properties of metals make them suitable for a range of uses. But mixing a metal with even a tiny amount of another substance (metal or non-metal) can dramatically change these properties. The metal mixture is called an alloy and tends to be more useful than a pure metal. Some examples of alloys that are commonly used are bronze (copper and tin), brass (copper and zinc) and steel (iron and carbon).

Alloys can make metals more resistant to corrosion and make them harder and less malleable. This is because the presence of the atoms of another element disrupts the regular arrangement of the metal lattice, which means that the layers of atoms are no longer able to slide over each other as easily. In a pure metal, because the metallic bonds are constantly forming and reforming between different ions and the delocalized electron cloud, if a layer of atoms moves, the bonds reform so the substance does not break when hammered (malleable) and can be drawn out into thin wires (ductile).

Iron is by far the most widely used metal today. You will be exploring the extraction of iron in Chapter 10, but the following activity explores some of iron's alloys and uses.

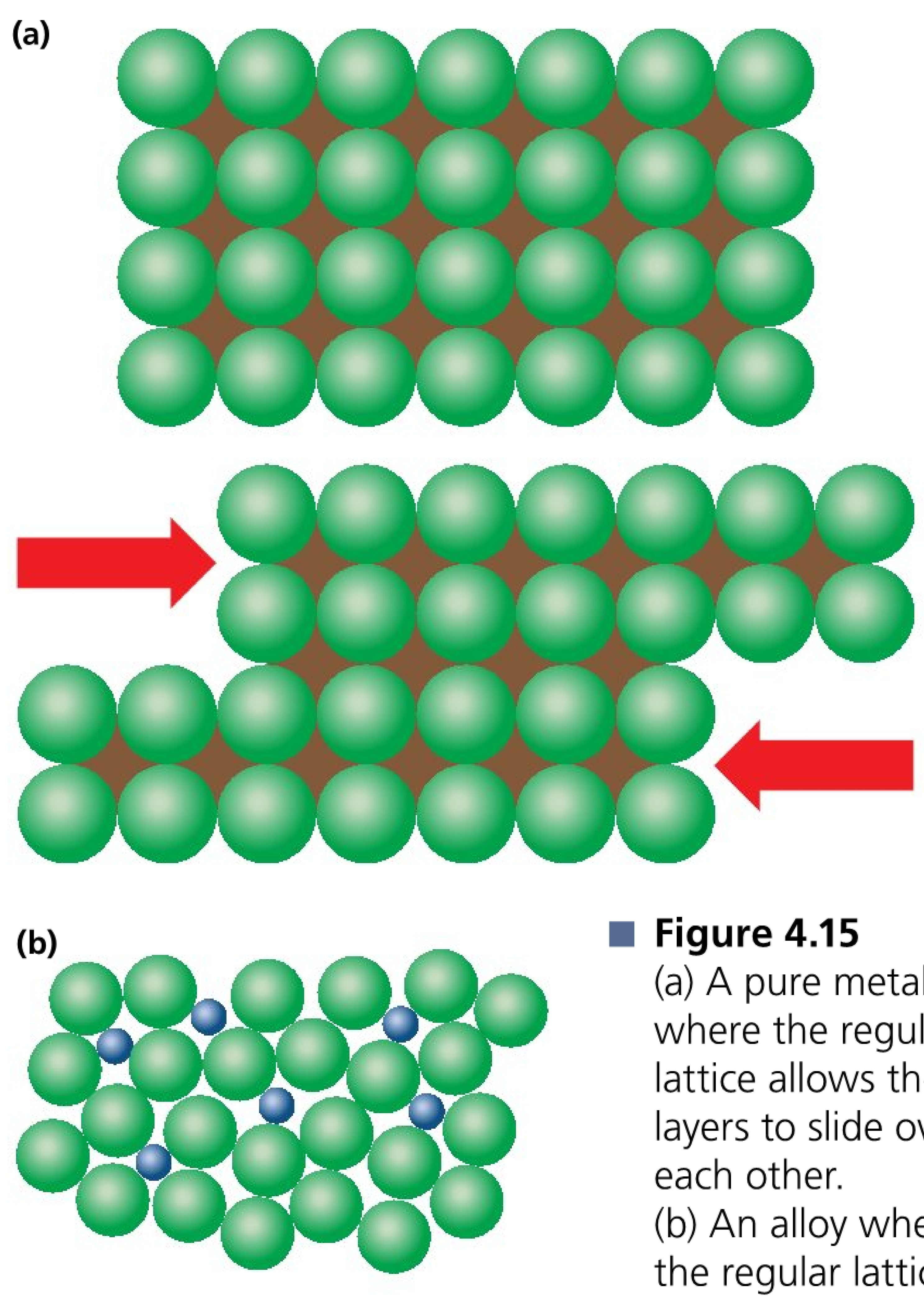


Figure 4.15
(a) A pure metal, where the regular lattice allows the layers to slide over each other.
(b) An alloy where the regular lattice is disrupted, changing the properties of the main metal element.

ACTIVITY: The many faces of iron

ATL

- Communication skills: Read critically and for comprehension; Make inferences and draw conclusions; Preview and skim texts to build understanding

Carry out research to answer the following questions on how changing the elements and/or the quantities of the different elements in an alloy can produce products with vastly different properties.

1. When iron is extracted from the blast furnace, the product is called pig iron. This has limited uses so is usually converted into cast iron. **State** the composition of different elements in cast iron. **Outline** what products cast iron is used to make and, making reference to its properties, **describe** why it is used for these products.
2. **State** how wrought iron is different from cast iron. **Describe** its uses, making reference to its properties.
3. **Draw** a diagram to show how the particles are arranged in pure iron and how they are arranged in an iron–carbon alloy.

Hint

Carbon is a much smaller atom than iron and this should be reflected in your diagram.

4. **Explain** how the properties of the alloy are different from those of iron.
5. **Identify** the components of stainless steel and some of its everyday uses.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

ACTIVITY: Map it out!

ATL

- Communication skills: Make effective summary notes for studying; Organize and depict information logically
- Organization skills: Use appropriate strategies for organizing complex information; Understand and use sensory learning preferences (learning styles)

In this task you will **create** a concept map to **summarize** the bonding that occurs in elements and compounds. The map is shown in Figure 4.16 and is blank with the exception of the box at the top, which will be your starting point. Copy the map structure into your book and then allocate the words in the blue box to each of the blank boxes to **create** a bonding summary.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

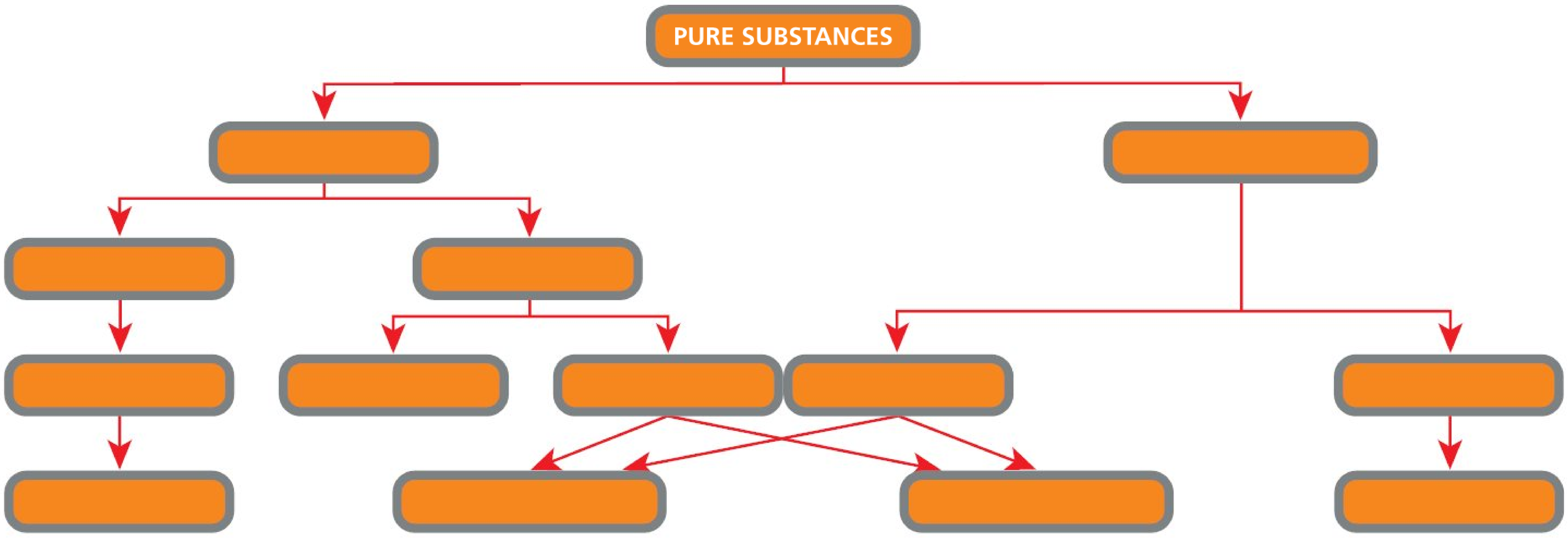
HEADLINE

If you were to write a headline for this topic or issue right now that captured the most important aspect that should be remembered, what would that headline be?

EXTENSION

In Chapter 3, you met some of the horrors of gas warfare in the First and Second World Wars. But science's contribution to wars did not end there. During the First World War, Germany started to exploit a different area of the periodic table – the transition metals. **Find out** about the scientific and technical innovation that led to the 'Big Bertha' siege guns used by the German military.

As technology develops, we better understand how to take advantage of the materials that we have and how to manipulate and alter them so that they meet our ever-changing needs. So what do you think: can we improve on the materials nature has provided?



■ **Figure 4.16** Create your summary concept map of bonding

These are the words to be allocated to the blank boxes. You may need to repeat words.

metal	compound	metallic lattice
non-metal	ionic bonding	separate atoms (noble gases)
metal + non-metal	covalent bonding	simple covalent molecules
non-metal + non-metal	metallic bonding	covalent network solids
element	ionic lattice	

ACTIVITY: Ionic, covalent or metallic?

ATL

- Creative-thinking skills: Make guesses, ask 'what if' questions and generate testable hypotheses; Create novel solutions to authentic problems
- Communication skills: Organize and depict information logically
- Organization skills: Use appropriate strategies for organizing complex information; Plan short- and long-term assignments; Meet deadlines
- Critical-thinking skills: Gather and organize relevant information to formulate an argument

In this chapter you have been introduced to the different properties that substances have and how these properties depend on the bonding present. For this assessment, you have been given five substances, A, B, C, D and E, and your task is to plan a laboratory experiment that will determine the properties of each substance, hence the type of bonding present.

Use the MYP *Sciences Inquiry Cycle* in Chapter 1 to structure your report. It should **explain** the problem that is going to be tested, **state** a hypothesis which should be **explained** using scientific reasoning, **explain** how all of the variables will be manipulated and how sufficient and relevant data will be collected and **describe** a logical, complete and safe method.

As the substances here are unknown, it is not possible to formulate a hypothesis about what structure each specific one has, so it might be useful to set out your hypothesis as a decision flow chart. The hypothesis must be supported by specific reference to the scientific background.

Assessment opportunities

- This activity can be assessed using Criterion B: Inquiring and designing.

How do we write word and balanced symbol equations for chemical reactions?

The next few sections will take you through the steps to write a balanced symbol equation for any reaction that you might encounter in your MYP Integrated Sciences programme. We are going to start by extending the naming of compounds to include compounds that are made of polyatomic ions (look at the blue box).

WORD EQUATIONS

Scientists can summarize the transformation that occurs in a chemical reaction using a word equation. A word equation will tell you what the reactants are (the substances on the left of the equation) and what the products are (the substances on the right of the equation); the reactants and products are separated by a forward-facing arrow.

reactant + reactant → product

This is a word equation for the complete combustion of methane:

$$\underbrace{\text{methane + oxygen}}_{\text{reactants}} \overbrace{\rightarrow}^{\text{forward-facing arrow separating reactants and products}} \underbrace{\text{carbon dioxide + water}}_{\text{products}}$$

Hint

Never include an equals sign (=) instead of a forward-facing arrow to separate the reactants and products. In a chemical reaction new substances are formed; these new substances have different properties to the starting materials. The arrow shows that the reactants make, or produce, the products but they are not the same as each other.

Naming ionic compounds with a polyatomic ion

A **polyatomic ion** is a charged particle that is made up of different atoms, covalently bonded together. The group of atoms behaves as a single unit, and the charge applies to the unit as a whole. Most polyatomic ions (also known as **compound ions** or **molecular ions**) have an overall negative charge and contain oxygen. Although the ion consists of covalently bonded atoms, since it is charged it will form an ionic bond with an oppositely charged ion.

Before being able to name compounds that contain these ions, you need to be able to identify and name the polyatomic ions. Here are some guiding points.

- When the polyatomic ion is made up of two different elements, one of which is oxygen, the name of the polyatomic ion will be the name of the non-oxygen element, with a suffix of 'ate'. For example CO_3^{2-} is carbonate; SO_4^{2-} is sulfate.
- If hydrogen is also present, the name hydrogen precedes the rest of the name. For example, HCO_3^- is hydrogencarbonate; HSO_4^- is hydrogensulfate.
- Sometimes polyatomic ions can exist with fewer oxygen atoms than the maximum. The suffix then changes to 'ite'. For example SO_3^{2-} contains one fewer oxygen than SO_4^{2-} so is sulfite.

ACTIVITY: Names, names, names!

ATL

- Critical-thinking skills: Interpret data
- Information literacy skills: Use memory techniques to develop long-term memory

1 **Deduce** **the names of the ionic and covalent compounds in Table 4.3. Practise with more examples of the compounds you already know how to name and then try some new ones.**

Hint

Remember that the subscripts are only included in the name when dealing with covalent compounds.

2 **Suggest** **what additional information, other than the name of the compound, the formulae of the compounds provide you with.**

So how do you name compounds of polyatomic ions?

- If the polyatomic ion is positively charged
  - the name of the polyatomic ion comes first
  - the name of the other substance comes second.
    - If it is a non-metal, the ending of the element name changes to 'ide'. For example NH_4Cl is ammonium chloride.
    - If it is a negatively charged polyatomic ion, the name stays the same. For example NH_4NO_3 is ammonium nitrate.
- If the polyatomic ion is negatively charged
  - the name of the metal or positive polyatomic ion comes first and stays the same
  - the name of the polyatomic ion comes second and also stays the same. For example $Mg(HCO_3)_2$ is magnesium hydrogencarbonate.
  - If the metal is a transition metal, the charge/chemical form of the metal is indicated as a roman numeral in brackets after the name of the metal. For example $CuSO_4$ is copper (II) sulfate.

Formula (maximum number of oxygen atoms)	**Name**	**Formula (if there are fewer than the maximum number of oxygen atoms)**	**Name**
NH_4^+	ammonium*		
SO_4^{2-}	sulfate	SO_3^{2-}	sulfite
HSO_4^-	hydrogensulfate	HSO_3^-	hydrogensulfite
CO_3^{2-}	carbonate		
HCO_3^-	hydrogencarbonate		
NO_3^-	nitrate	NO_2^-	nitrite
PO_4^{3-}	phosphate		
OH^-	hydroxide		

* This is the only positively charged ion. It is also the only one that does not contain the element oxygen.

■ **Table 4.2** Names and formulae of polyatomic ions you need to be familiar with

Formula	Formulae	Formula	Formula
LiCl	Cu_2O (copper charge 1+)	NO	CO
K_2S	Fe_2O_3 (iron charge 3+)	CO_2	$BaSO_4$
ZnO	NaOH	HI	$Mg(NO_3)_2$
$PbBr_2$ (lead charge 2+)	K_2SO_3	NF_3	NH_4HCO_3
Na_2O	$CaCO_3$ (chalk)	SO_2	Li_3PO_4
KI	$NaNO_3$	SF_6	$Ca(OH)_2$

■ **Table 4.3** Deducing the names of ionic and covalent compounds

3 **Evaluate the usefulness of having globally accepted rules for nomenclature (naming compounds).**

4 **Divide yourselves up into groups of at least four. Take three pieces of plain A4 white paper and cut each into eight equally-sized rectangles. Write the formula and name of each of the substances in Table 4.3 on a separate piece of paper, turn them all upside down and mix them up. Play a game of 'Names and formulae pairs!'**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

ACTIVITY: Writing word equations

ATL

- Communication skills: Negotiate ideas and knowledge with peers; Organize and depict information logically
- Information literacy skills: Make connections between various sources of information

Being able to predict the product(s) of a chemical reaction is a fundamental step to being able to write word equations for reactions. Work with a partner to **formulate** word equations for the following reactions. Use the knowledge you have acquired in previous chapters to first **deduce** the products.

Hint
See Chapter 3 for chemical reactions of group 1 and group 17 elements.

1. **The reaction between magnesium and chlorine**
2. **The burning (combustion) of carbon**
3. **The addition of lithium to water**
4. **The displacement reaction between chlorine and potassium bromide**
5. **The tarnishing of sodium in air**
6. **The thermal decomposition of calcium carbonate**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

CONVERTING WORDS TO FORMULAE

How can we express the names of elements and compounds as formulae?

Elements

The formula of most elements is their symbol in the periodic table. For example, whether sodium is a reactant or product, its formula is Na. There are however some exceptions:

- diatomic molecules: H_2, O_2, N_2, F_2, Cl_2, Br_2, I_2
- sulfur: S_8
- phosphorus: P_4

Covalent compounds

The formula of a covalent compound depends on the number of each type of atom present, which is indicated by the name of the compound. The number of each type of atom is represented in a formula by a subscript immediately after the symbol. For example:

- 'sulfur dioxide' tells us there is one sulfur atom and two oxygen atoms; the formula therefore is SO_2
- 'dibromine monoxide' tells us there are two bromine atoms and one oxygen atom; the formula therefore is Br_2O
- remember, covalent compounds containing more than one hydrogen atom don't include a prefix with the number of hydrogen atoms present. For example hydrogen chloride is HCl and hydrogen sulfide is H_2S.

To determine the formula of a hydrogen-containing compound, you can draw the Lewis structure.

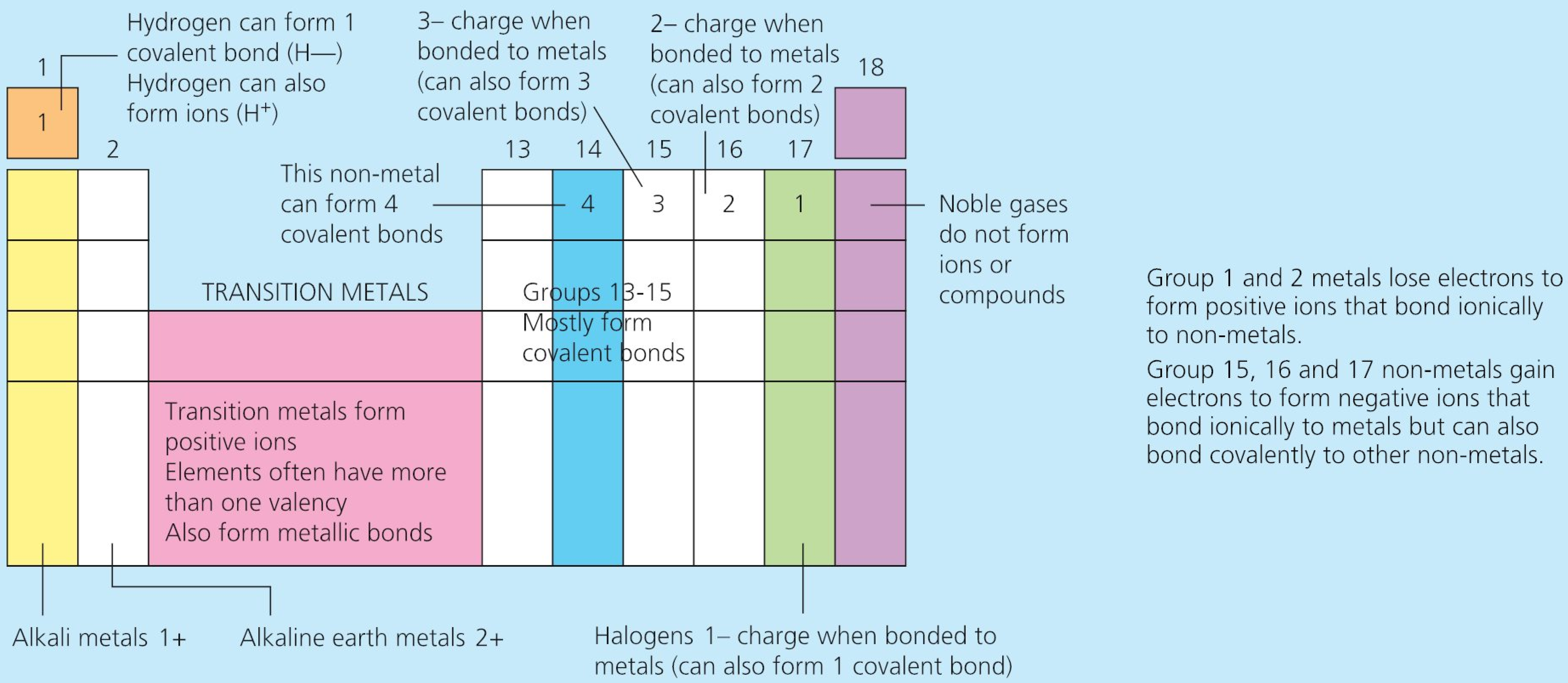
Ionic compounds

The dot-and-cross diagram of an ionic product shows the number of ions of each element present. This gives the formula of the ionic compound. This can also be determined by an alternative method, using charges. Both methods have the same underlying concept: the reacting atoms want to complete their shells in order to become stable and they do this by transferring electrons from one to the other, forming ions with charges, and these charges must balance so that the resulting compound is neutral.

The charge on the ion is a measure of the element's **valency**. Valency is the combining power of an element or how many bonds it is able to make.

The steps for determining the formula of an ionic compound using charges are as follows:

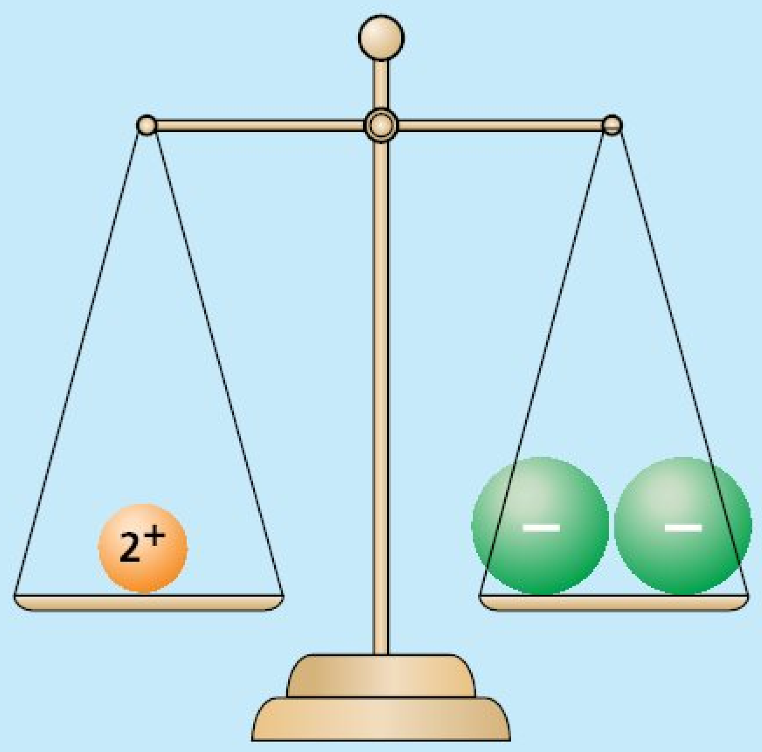
1. Determine the charge of the ion by identifying what group of the periodic table the element is in; this will tell you how many electrons it needs to gain or lose in order to have complete shells and the resulting charge on the ion. Use Figure 4.17 to help you with this.



■ **Figure 4.17** The charge of the ion depends on its position in the periodic table

2 Duplicate the ions where necessary until the opposite charges are balanced and overall the compound is neutral.

3 Deduce the formula. If more than one of any of the ions is needed to balance the charges, the number of ions is indicated with a subscript after the symbol. If there is only one of an ion present, no subscript is included.



■ **Figure 4.18** Imagine the balancing of charges like the balancing of items on scales

Worked example: Ionic compounds

Example: Deduce the formula of calcium bromide

Step 1:	Calcium	Bromine
	Ca	Br
Charge of ions	Group 2 → lose $2e^-$	Group 17 – gain $1e^-$
	Ca^{2+}	Br^-
Step 2: Add duplicates of the ions until the charges are balanced	Ca^{2+}	Br^- Br^-
	2+	2–
Step 3: Ionic formula	$CaBr_2$	

Hint

The charges are written with the number first, followed by the sign. If the charge is 1+ or 1–, the number is often not included.

Hint

Do not confuse the coefficient and the subscript. For example, the formula of magnesium chloride is $MgCl_2$. Here the '2' is a subscript and is needed to balance the 2+ charge of magnesium (Mg^{2+}) with the 1– charge of chloride (Cl^-). If you needed an additional magnesium ion, you would place a coefficient of '2' in front of $MgCl_2$ to give $2MgCl_2$; this means there are now two magnesium ions but also four chloride ions.

BALANCING EQUATIONS

Before you can write *balanced* symbol equations for chemical reactions, there is one final step to master: balancing equations. When a chemical reaction is expressed with chemical formulae, the number of atoms of each element on the reaction side must equal the number of atoms of the same element on the product side. This is because the **law of conservation of mass** states that in a chemical reaction, matter cannot be created or destroyed. So the total mass of the reactants must be equal to the total mass of the products. An analogy might be to think of the reaction as money: if you ask for change for a big value note, you will get back a lot of coins, but the total value should still be the same.

To change the number of atoms of an element, we add **coefficients** to the formulae.

You will notice that in the examples in the activity *Balance away*, there are letters in brackets following all of the formulae. These are called **state symbols**. State symbols are symbols that are used to show the physical state of the reactants or products taking part in the chemical reaction. They are:

- (s) – solid. This is used for almost all metals and all metal compounds.
- (l) – liquid. Water is an example of a liquid.
- (g) – gas. This is used for the elemental gases, as well as gaseous simple covalent compounds.
- (aq) – aqueous (dissolved in water). All acids and alkalis are aqueous as they are almost always dissolved in water. They would be (l) if they were pure. All soluble salts and solutions are aqueous.

Steps for balancing equations

1 Choose one of the elements present. It is usually easier to leave hydrogen and oxygen until last as they can appear in more than one reactant or product.

Hint

If you have the same polyatomic ion present as both a reactant and product, keep it as a group and start with that. For example, if you had silver nitrate ($AgNO_3$) as a reactant and magnesium nitrate ($Mg(NO_3)_2$) as a product, rather than look at the nitrogen and oxygen atoms individually, consider the number of nitrate groups and focus on them first.

2 Add up how many of that type of atom you have in the reactant and product side. Add coefficients until you have the same number of both.

3 Continue for the other elements. Remember that if you add a coefficient in front of a compound, you may upset the balance of another element that you have already balanced and may need to revisit it.

4 When all of the atoms are balanced, if one of the coefficients is a fraction, multiply all of the coefficients by the denominator of the fraction leaving only whole number coefficients. You must also ensure that all of your coefficients have been simplified as much as possible.

ACTIVITY: The home stretch

ATL

- Communication skills: Use and interpret a range of discipline-specific terms and symbols; Understand and use mathematical notation; Organize and depict information logically

Use everything that you have learnt in this section to write balanced symbol equations with state symbols for the reactions in the activity *Writing word equations* (page 88).

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

ACTIVITY: Balance away

ATL

- Communication skills: Use and interpret a range of discipline-specific terms and symbols

Deduce how the following equations should be balanced correctly. If they are already balanced, no coefficients need to be added.

1 $Mg (s) + F_2 (g) \rightarrow MgF_2 (s)$
2 $H_2 (g) + Cl_2 (g) \rightarrow HCl (g)$
3 $C_5H_{12} (l) + O_2 (g) \rightarrow CO_2 (g) + H_2O (g)$
4 $KOH (aq) + H_2SO_4 (aq) \rightarrow K_2SO_4 (aq) + H_2O (l)$
5 $Na (s) + H_2O (l) \rightarrow NaOH (aq) + H_2 (g)$
6 $SO_2 (g) + O_2 (g) \rightarrow SO_3 (g)$
7 $Cl_2 (aq) + NaI (aq) \rightarrow NaCl (aq) + I_2 (aq)$
8 $Al (s) + O_2 (g) \rightarrow Al_2O_3 (s)$
9 $N_2 (g) + H_2 (g) \rightarrow NH_3 (g)$
10 $CaCO_3 (s) + HCl (aq) \rightarrow CaCl_2 (aq) + CO_2 (g) + H_2O (l)$

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

ACTIVITY: Finding the formula of magnesium oxide experimentally

ATL

- Creative-thinking skills: Make guesses, ask 'what if' questions and generate testable hypotheses; Make unexpected or unusual connections between objects and/or ideas
- Critical-thinking skills: Draw reasonable conclusions and generalizations; Gather and organize relevant information to formulate an argument; Interpret data

In this experiment, you will react magnesium ribbon with oxygen in order to **determine** the formula of the magnesium oxide product experimentally. Your calculations will be based on the law of conservation of mass.

Equipment and materials (per group)

- Heatproof mat
- Tripod
- Pipe clay triangle
- Crucible and lid
- Bunsen burner
- Wooden splint
- Lighter
- Tongs
- Magnesium ribbon (approximately 10 cm long)
- Sandpaper
- Access to an electronic balance

Safety: Safety goggles should be worn throughout the experiment, hair should be tied back and you should stand while carrying out the experiment. The equipment will get very hot. This poses one of the biggest hazards so you should practise lifting the crucible lid and crucible with tongs before you begin. At the end of the experiment you must not touch the tripod or pipe clay triangle. If you do burn yourself on the equipment, you should run cold water over the affected area for at least 10 minutes.

Method

Before you begin, **formulate** a prediction about what you expect will happen to the mass of magnesium. **Explain** your answer.

1 **Take the piece of magnesium ribbon. It should be silver and shiny. If it is not, use the sandpaper to rub it down, then wind it loosely so that it forms a coil.**
2 **Place the magnesium ribbon on the electronic balance and record its mass.**
3 **Place the crucible with its lid on the electronic balance and record the mass.**
4 **Set up your equipment as in Figure 4.19, with the coiled magnesium in the centre of the crucible.**
5 **Light the Bunsen burner and heat the magnesium metal. During heating, with quick repetitive actions slightly lift the lid and replace it. Keep checking the magnesium until you no longer see it reacting.**

6 At this point, heat for another 2–3 minutes.
7 Turn off the Bunsen burner. Allow the equipment and product to cool down.
8 Find the mass of the crucible, lid and magnesium oxide product.
9 Return the crucible, lid and product to the pipe clay triangle, relight the Bunsen burner and heat for a few more minutes. After it has cooled, weigh the crucible, lid and product again, repeating this step until the readings of the mass are consistent.

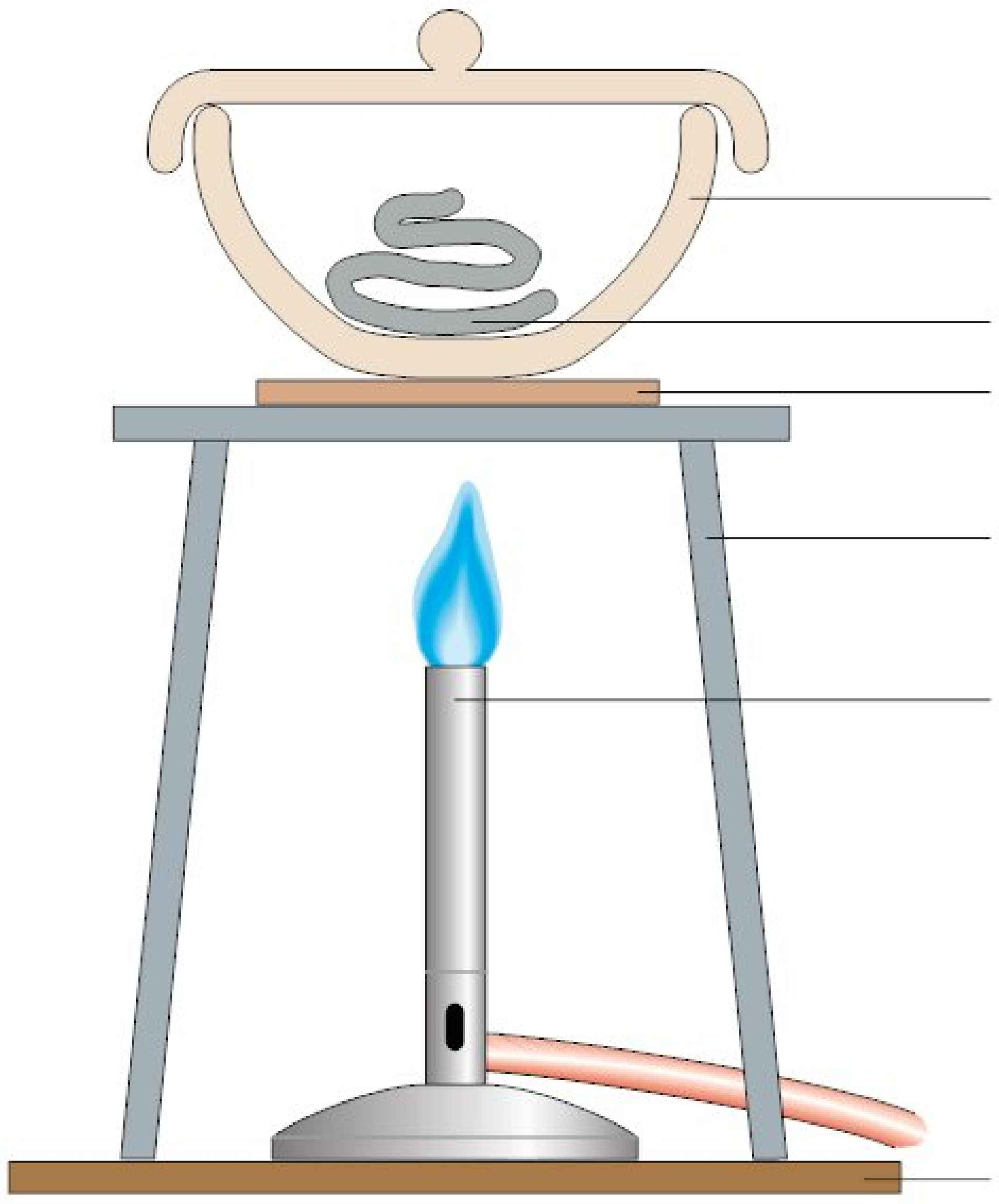


Figure 4.19 Experimental set-up for the burning of magnesium ribbon

Analysis

State evidence that a new substance was formed. **Formulate** a balanced symbol equation for the reaction, ensuring you also include state symbols. **Suggest** why you lifted the lid repeatedly during the reaction. Why must you not leave it off for too long?

Calculate the mass of the product using the information you have recorded.

Deduce the mass of oxygen that must have reacted with the magnesium. **Calculate** the amount of magnesium (moles) and the amount of oxygen (moles) that reacted by dividing the mass of each element by its relative atomic mass.

Determine the ratio of amount (moles) of magnesium to amount (moles) of oxygen. This ratio is the ratio of magnesium to oxygen in the product. Use this ratio to **determine** the formula of the product, from the experimental evidence.

Does this agree with the actual formula of magnesium oxide? Whether your formula did or not agree, **evaluate** your experiment, making specific reference to factors that could have affected your results.

◆ Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding and Criterion C: Processing and evaluating.

What do forces do? How do forces work together?

■ **Figure 4.20** A tug of war

ARE YOU BALANCED?

Have you ever taken part in a tug of war? Tug of war is an international sport and has its own association. It was even once an Olympic event! The Tug of War Association has a YouTube channel. **Watch** one of their videos: **www.youtube.com/user/kcorin1**

In a tug of war, forces are working through physical contact. Each team exerts a pulling force on the other and the object of the game is to pull the opposing team far enough such that a mark on the rope moves over the centre point. What is happening in the tug of war when the teams are equally matched and nobody is moving?

To analyse situations involving forces, we can represent the forces using arrows such that:

- the arrow points in the direction that the force is acting, starting on the object it is acting on
- the length of the arrow is proportional to the size of the force.

We might use a scale diagram to make sure our force arrows represent systems of forces accurately; for example, 1 cm = 1 N. We can also define the direction of the forces relative to fixed axes in space that we choose, for example the x- or y-axes.

ACTIVITY: Tug-of-war mind experiment

ATL

- Creative-thinking skills: Make guesses, ask 'what if' questions and generate testable hypotheses

This is a 'mind experiment', where we try to figure out what will happen based on our *experience* and on our *imagination.*

With a partner: take a short piece of string and mark its centre point with a felt-tip pen or similar. Tie the string around each person's little finger and pull! Take care not to pull too hard or hurt each other.

Now **think–pair–share** your ideas about these questions:

When the two teams are each pulling by the same amount and neither is moving …

- **Is there a force in the rope?**
- **What will happen if the rope is cut?**
- **If you placed a force meter in the rope, what would you predict that it should read?**

Links to: Mathematics

A force arrow is an example of a **vector**. Vectors are used in mathematics to solve problems in geometry and, more generally, topology (the mathematics of space).

The following diagrams show the forces in tug-of-war contests. The arrows are drawn to a scale of 1 cm = 20 N. In each case, force towards the right is defined as positive.

For each diagram, decide:

- which way the teams will go
- the size of the force moving them that way (in newtons).

(The first contest has been done for you!)

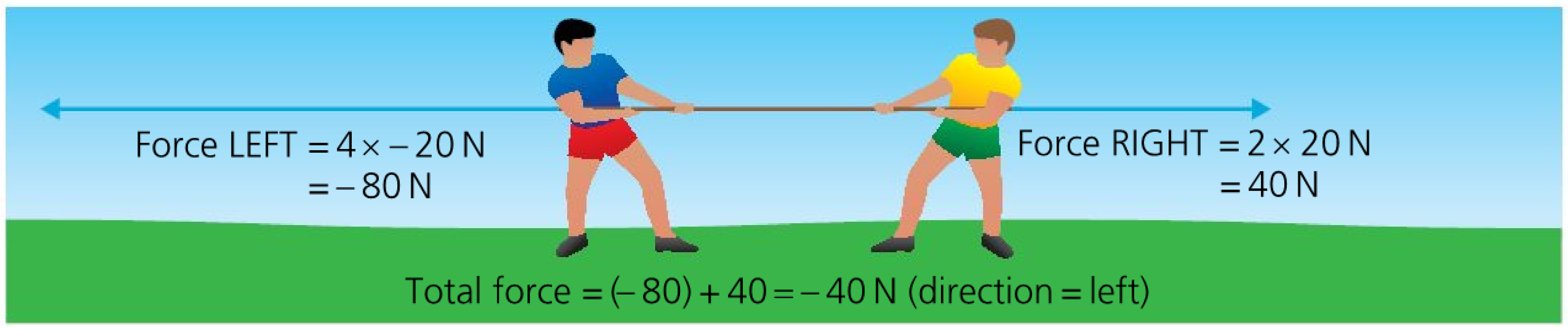


Figure 4.21 Tug of war, contest 1

Force **left** = 4 × 20 N = –80 N

Force **right** = 2 × 20 N = +40 N

Total force = (–80) + 40 = –40 N (direction = left)

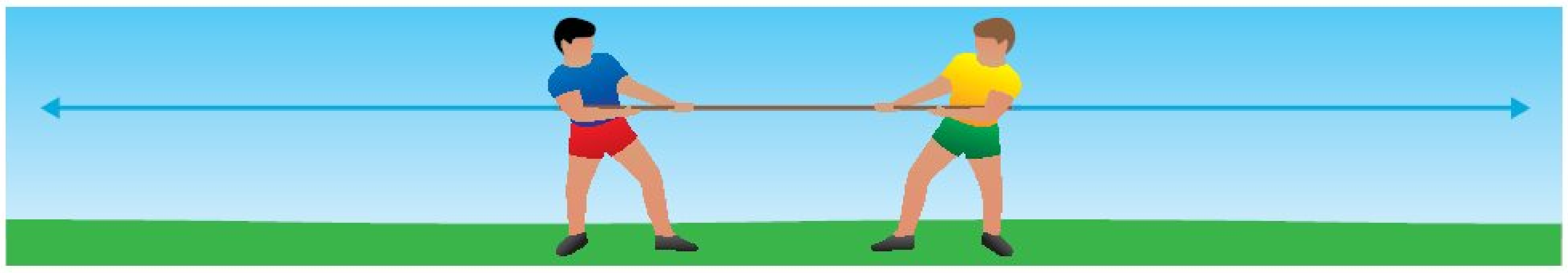


Figure 4.22 Tug of war, contest 2

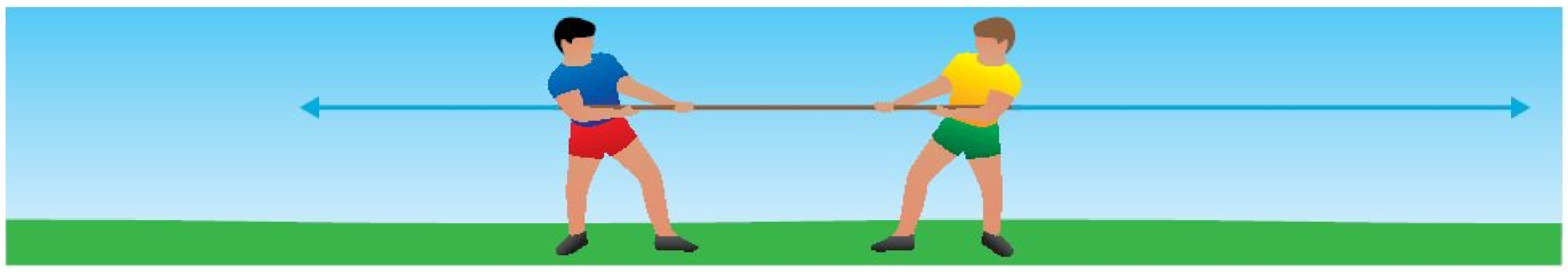


Figure 4.23 Tug of war, contest 3

ACTIVITY: Weight and reaction

ATL

- Critical-thinking skills: Practise observing carefully in order to recognize problems

Describe what would happen to these forces in Figure 4.24 if you leant down on top of the books?

- **Is it possible for $W > R$? What would happen?**
- **Is it possible for $R > W$? What would happen?**

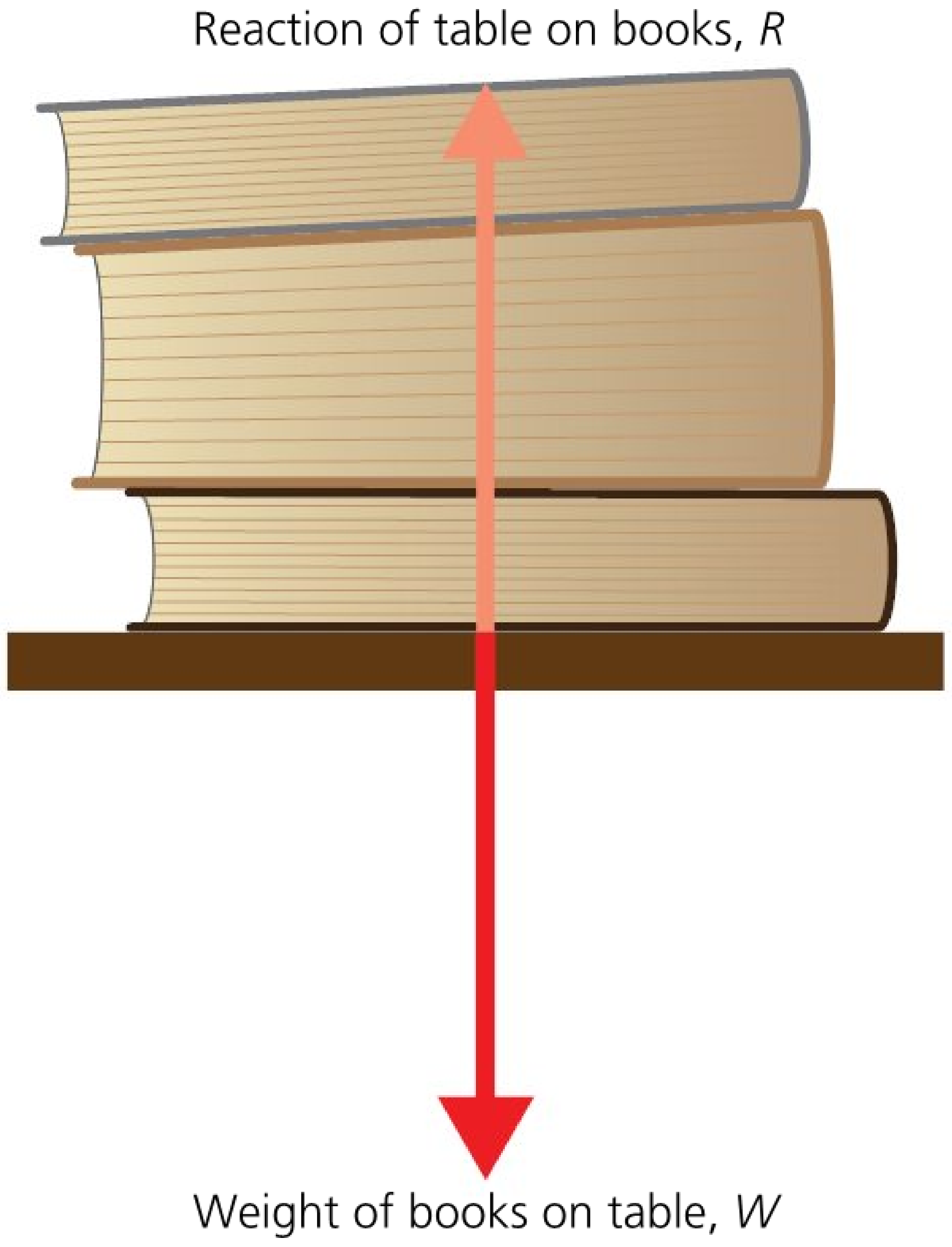
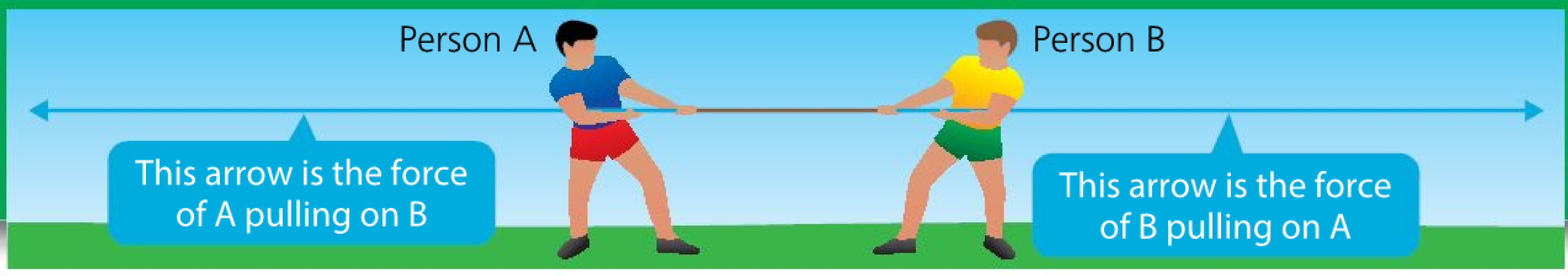


Figure 4.24 Static forces in action



■ **Figure 4.27** Force shown in tug of war, contest 1

Explain what is happening in Figures 4.25 and 4.26 in terms of *R* and *W*.

■ **Figure 4.25** *In the photo, the greatest force is … because …*

■ **Figure 4.26** *In the photo, the greatest force is … because …*

The blue force arrows in the diagrams on page 94 show the force that each person is applying to the rope. However, we might just as well have drawn force arrows to show *the force each person experiences due to the other person*. Figure 4.27 shows contest 1 drawn this way.

But, of course, if we work out the sizes and directions of the forces we get:

Force **left** = 4 × 20 N = –80 N

Force **right** = 2 × 20 N = +40 N

Total force = (–80) + 40 = –40 N (direction is left)

So it makes no difference to the answer.

The rope can be thought of as experiencing forces in *either* direction, pulling *both* ways at once! So if we placed a newton meter in the rope, it would actually show *both* the forces present.

Total force on newton meter = 80 + 40 = 120 N

This force is called the **strain** in the rope.

In contest 2, the forces from A and B are exactly equal in size, but opposite in direction. In this case the forces seem to cancel out and neither team will move. We say that the forces are balanced and that the system is now in **static equilibrium**.

Of course this doesn't mean the forces have disappeared; they still act in the rope and a newton meter would measure the strain they produce.

When objects are stationary on Earth, they still have forces acting. In Chapter 2 we saw that the force of gravity acts everywhere on masses, so any mass within a gravitational field will experience a force due to that field.

For example, we know that any object sitting on a surface experiences the gravitational force acting on its mass as weight, W.

So why don't the books in Figure 4.24 crash through the table? Obviously, because the table stops them … by pushing back up with an equal and opposite amount to the weight. This 'push back' is called the **reaction**, R. If the reaction is in the same axis as the weight, it is also called the **normal force**, N.

You probably noticed that in the tug of war, the forces are always directly opposite to each other; if we choose the x-axis to be parallel to the rope, the forces are always parallel to the x-axis. Moreover, a rope can only sustain pulling force, or strain. In real life and with other materials, this isn't often the case. Real structural systems have to distribute load forces in multiple directions at the same time. With a little help from natural models, humans have learnt that particular shapes or unit structures do this well.

How do different structures distribute force? What is deformation?

ACTIVITY: Identifying strong structural shapes

ATL

- Critical-thinking skills: Practise observing carefully in order to recognize problems; Draw reasonable conclusions and generalizations

Look at the images of some famous buildings, old and new, in Figure 4.30.

Identify the strong unit shapes that are used in each building.

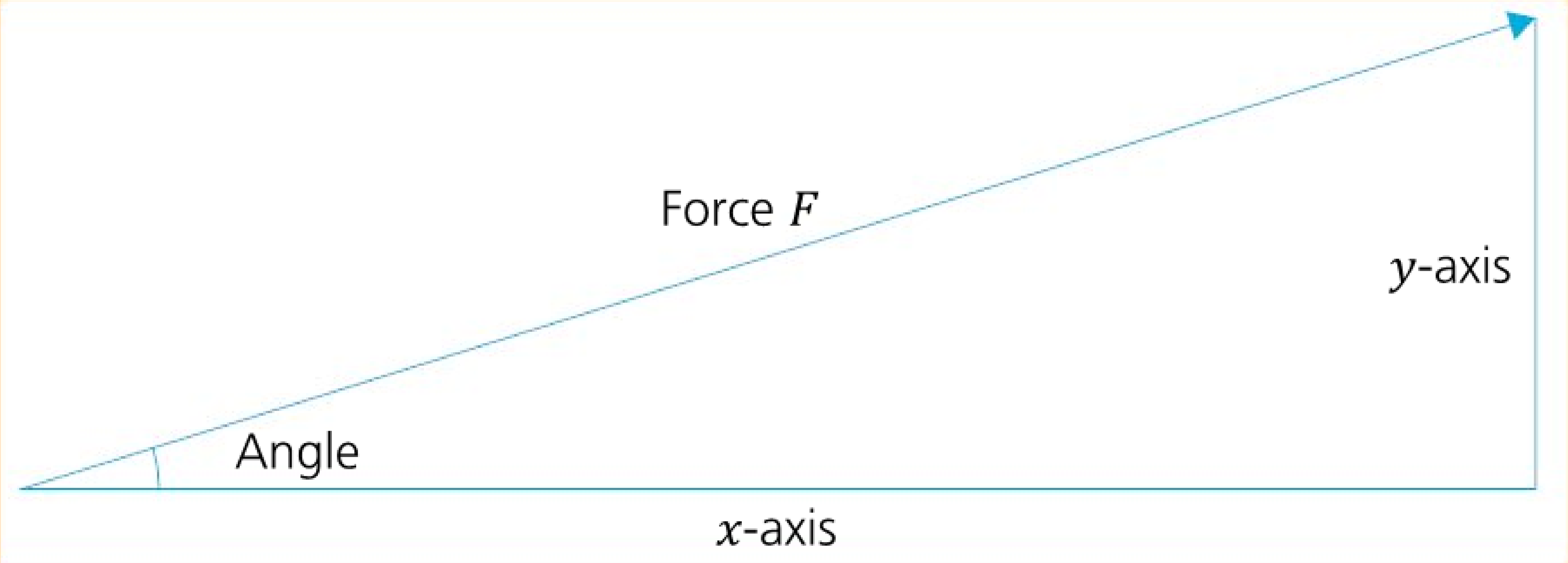
Using strips of thin card of the same dimensions, make five models of each of these shapes, all the same size.

In the activity *Identifying strong structural shapes*, you will notice that the shapes begin to change as you apply load. This change of shape is called **deformation**. Of course, the amount of deformation depends not only on the shape of the structure but also on the material it is made from, as we will explore shortly. If we wish to analyse the way forces work in two dimensions, we need to do a little mathematics.

Links to: Mathematics

Trigonometry

We can calculate the size of the 'effect' a force has in a certain direction by using trigonometry. We think of a force as making a triangle with the x- and y-axes like this:



■ **Figure 4.28**

Then we label the sides relative to the angle as 'opposite' and 'adjacent.' The longest side has a special name: it is called the hypotenuse.

The ratios of these sides are then defined as:

$$\text{sine (angle)} = \frac{\text{opposite side}}{\text{hypotenuse}}$$

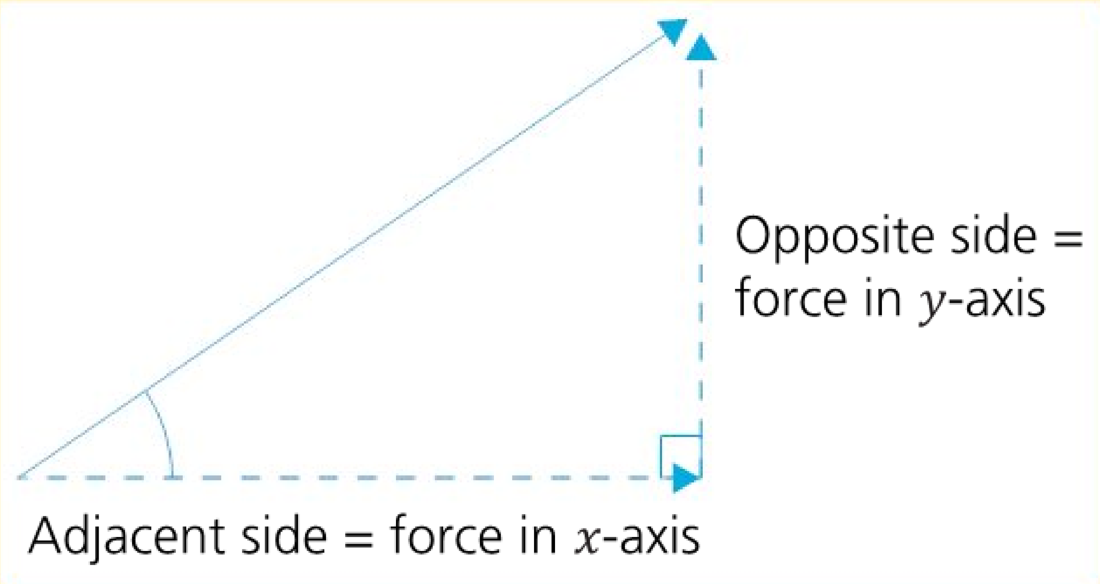
$$\text{cosine (angle)} = \frac{\text{adjacent side}}{\text{hypotenuse}}$$

Rearranging

opposite side = hypotenuse × sine (angle)

adjacent side = hypotenuse × cosine (angle)

This means that if we know the hypotenuse and the ratios (sine or cosine), we can work out the lengths of the sides of the triangle. See Figure 4.29.



■ **Figure 4.29**

If our triangle is formed from a *force*, then

opposite side = how much of the force is pulling in the *y*-axis

adjacent side = how much of the force is pulling in the *x*-axis

For example, if the angle = 30°, then

sine 30 = 0.5

cosine 30 = 0.866

A force of 1 N at 30° therefore pulls with approximately 0.9 N in the *x*-axis and 0.5 N in the *y*-axis!

Fix the card shapes to your work surface, side by side, with sticky tack or similar.

Place a plastic ruler across the top of the shapes.

Now use masses to **explore** what happens when you place a load on top of the shapes. **Observe** the changes in the shapes closely.

Take photographs as you add the masses. Upload the photographs to your computer or other device.

Analyse your images and **annotate** them by adding force arrows to show how you think each of the structures distributes the load applied to it.

Describe any changes you observe. **Summarize** your findings in a brief conclusion. In your conclusion, **evaluate** the advantages and disadvantages of each of the strong shapes.

■ **Figure 4.30**

◆ Assessment opportunities

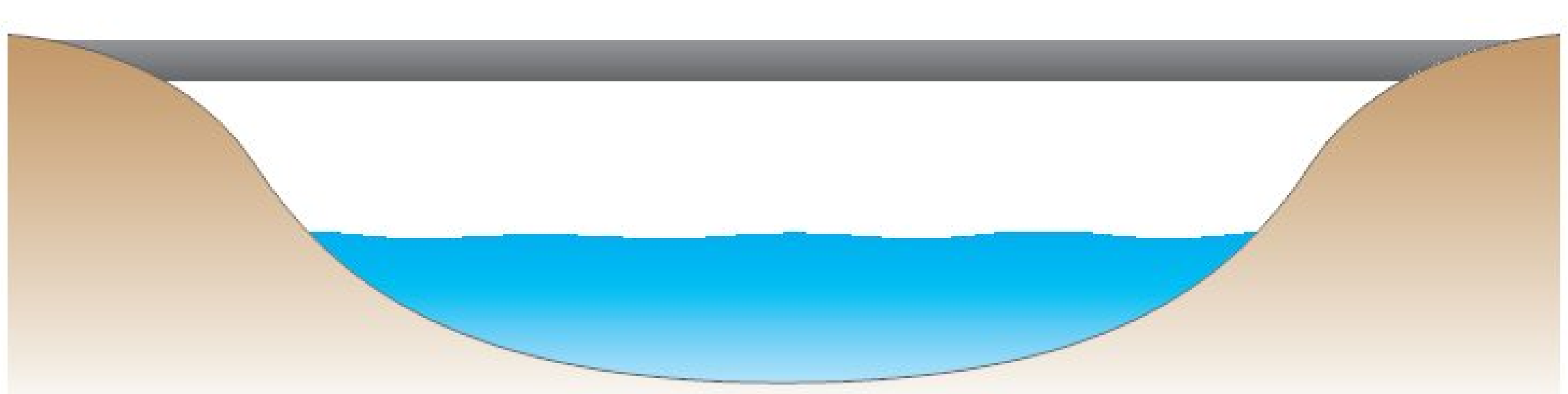
- In this activity, you have practised skills that are assessed using Criterion A: Knowing and understanding.

HOW DOES A TRIANGLE DISTRIBUTE FORCE?

When a load is applied to the point of an equilateral triangle, the two sides beneath the load – known as the **trusses** – are subject to **compression**; that is, the forces are 'squashing' or pressing down on the material in the side. The tendency for these sides is to spread outwards, but the bottom-most side – known as the **tie** – holds them in position and so is placed under tension.

BRIDGING THE GAP

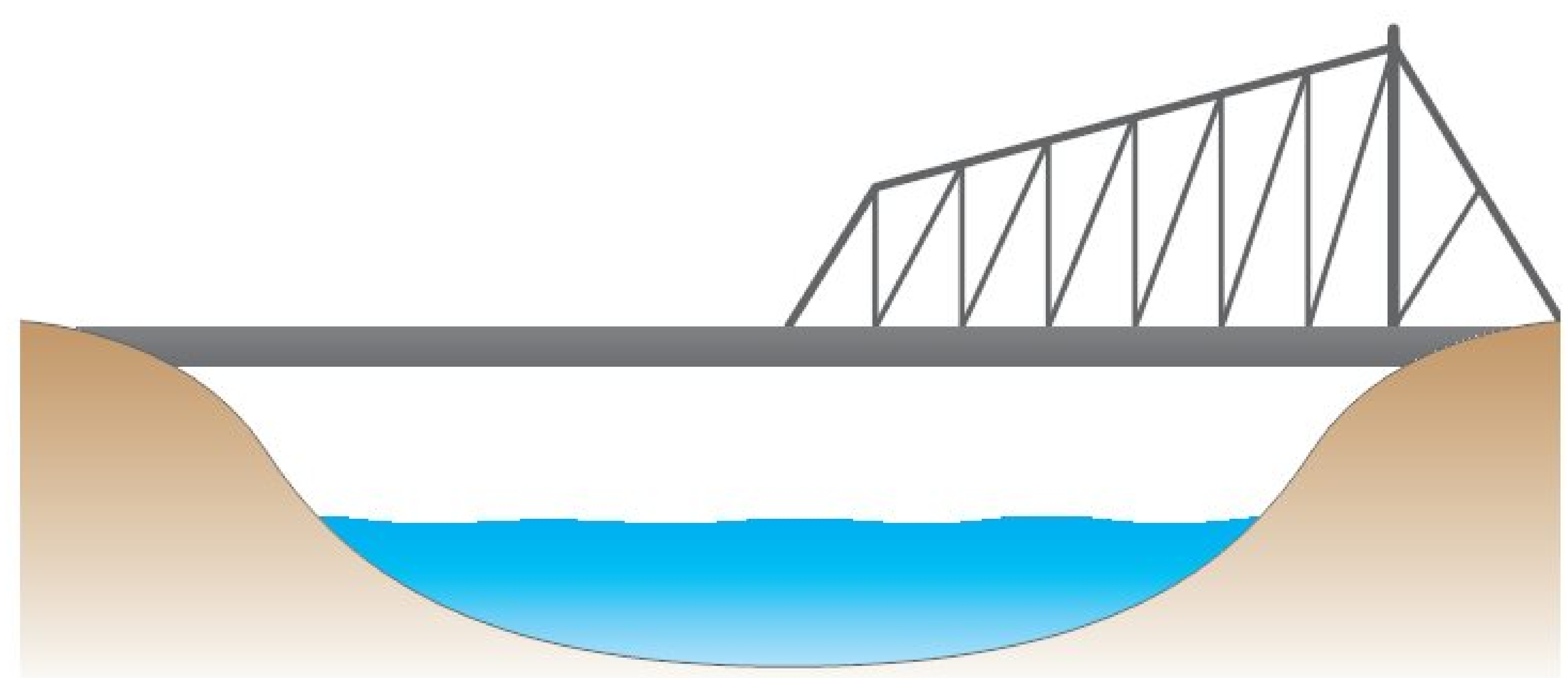
If we want to make a bridge across a gap, the simplest possibility is to lay a beam or bar across the gap (see Figure 4.31).



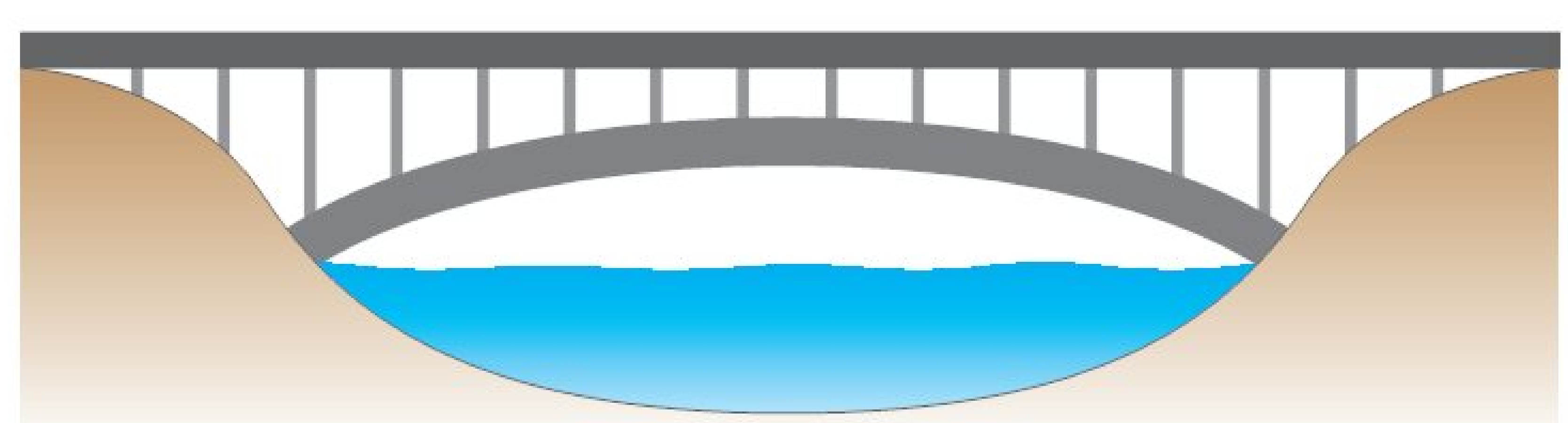
■ **Figure 4.31**

When load is applied to the centre of the beam, how will the beam deform? Another way to solve the problem of beam deformation is to add support above it. This arrangement is called a **cantilever** (Figure 4.32).

And still another possibility is to bend the beam to provide support at either end. This arrangement is called an **arch** (Figure 4.33).



■ **Figure 4.32**



■ **Figure 4.33**

Try online bridge simulations: search **bridge simulator** to experiment with different bridge designs.

The cantilever structures we have seen can respond to a load force applied along their length in two ways. Firstly, they could bend or deform as we have seen. Another possibility is that the whole structure moves. The effect of applying a force at the free end of a fixed cantilever is to make the beam turn around the fixed end. You may recognize that this forms a turning force or moment, where

moment (torque) = force × distance from **fulcrum**

If the force is given in N and the distance in m then the units of moment are N m.

■ **Figure 4.34** Extreme deformation is caused by earthquakes

■ **Figure 4.35** Carbon fibre running blades

HOW DOES FORCE AFFECT MATERIALS? HOW FAR CAN WE IMPROVE ON NATURAL MATERIALS?

Deformation occurs when a material's form is changed by force. Some materials can sustain deformation temporarily and then return to their original form; these are **elastic materials**. Others – such as modelling putty or the examples shown in Figure 4.34 – retain their new form and are then said to be **plastic**. Most materials pass through both phases; they remain elastic for a certain range of force, but after that the forces cause permanent change in their molecular structure.

Search **slow motion snapping steel rod** to watch a video filmed at very high speeds showing how steel snaps under extreme force.

During the elastic phase, the **extension** produced in the material is proportional to the load applied and Hooke's law applies:

$$F = -kx$$

where F is the load applied (N), x is the extension (m) and k is a constant called the **spring constant** (if a spring is being tested) or **coefficient of elasticity**. Note that x is the extension produced by the force; that is, it is the additional length stretched (or compressed) by the material when the force is added.

After the **elastic limit**, the material becomes plastic and deformation is permanent. Eventually, the material reaches **breaking or yield point**.

Sometimes we might want the material to be as elastic as possible. Figure 4.35 shows a running blade used by athletes in para-athletic games. The material in the blades is usually **carbon fibre**, which is a **polymer** reinforced by strands of graphite. Carbon fibre is also used in high-performance vehicles such as Formula One racing cars or sports bicycles as it is very light.

Worked example

A bungee jumper has mass 90 kg and wants to jump from a bridge that is 20 m above the ground. Her bungee elastic has length 5 m when unstretched. What coefficient of elasticity should her bungee have if she is to jump safely?

Solution

$$F = W = mg$$

So,

$$F = 90 \times 10 = 900\,\text{N}$$

The extension produced in the bungee elastic should be no more than

$$x = 20 - 5 = 15\,\text{m}$$

From Hooke's law

$$k = \frac{F}{x}$$

$$k = \frac{900}{15}$$

So the coefficient of elasticity should be at least $k = 60\,\text{N}\,\text{m}^{-1}$.

ACTIVITY: Flexing it

ATL

- Creative-thinking skills: Use brainstorming to generate new ideas and inquiries
- Collaboration skills: Listen actively to other perspectives and ideas
- Communication skills: Use appropriate forms of writing for different purposes

Work in pairs. You are sports engineers working for a para-athletic sports company. You have been given the task of **investigating** the elastic properties of some different materials that could be used for some low-cost running blades. The materials are:

polycarbonate plastic aluminium
steel

Your task is to **design** an investigation to **measure** the bending strength and elasticity of the different materials. Use the MYP *Sciences Inquiry Cycle* to **design** your investigation. Try to think of *two* different ways to carry out the experiment and **evaluate** each with your partner. Then decide collaboratively on the method you will use.

When you design your method, consider the following:

- **How will you measure the degree of deformation in the material accurately?**
- **How will you present your results in order to compare the different materials across a range of possible loads?**

Hint

See 'Measurement with parallax correction' below.

Safety: When applying loads to materials, it is possible that you will reach their yield point. When the materials snap, they will do so unpredictably and shards of material will be thrown out. Carry out your experiment with a safety screen to protect you. Wear suitable laboratory eye protection at all times.

Individually: When your experiment is complete, **summarize** your findings in a report for the marketing department of your company. Which material do you recommend? **Explain** your reasoning with reference to the scientific data you have gathered, but also to other factors that might be important to consider when manufacturing the low-cost running blades.

Assessment opportunities

- This activity can be assessed using Criterion B: Inquiring and designing and Criterion C: Processing and evaluating.

Measurement with parallax correction

Parallax is caused when a change of view point causes the apparent position of an object to change. You can experience this by looking at a distant object – a sign post or lamp post for example – and identifying another object behind it. When you walk to one side, you will see the position of the sign post appear to change relative to the object behind it.

Parallax can also affect the measurements we make when we use a needle on a gauge of some kind.

One way to avoid parallax error is to ensure that you always position your eye at the same level as the needle on the scale you are using for measurement. However, this can be hard to judge. A more reliable method is to use a mirror placed behind the needle. When the image of the needle is covered by the needle itself, then your eye is in the right position to read the gauge accurately.

Links to: Design

When designers imagine new objects or solutions to design problems, they have to account for many factors. Scientific and engineering variables, such as physical properties of materials and forces are very important, but when considering how to design objects that people will see and experience, designers must also account for aesthetic considerations in order to make the objects attractive or pleasant. And, of course, it is a fact of contemporary life that a designer must also work within the economic parameters of a project, sticking to the budget!

Take action: Supermaterials for superhumans?

ATL

- Communication skills: Use a variety of speaking techniques to communicate with a variety of audiences; Share ideas with multiple audiences using a variety of digital environments and media

! In this chapter we found out about new materials such as graphene or fullerenes. We also analysed how force affects structural shape (deformation) and saw how this knowledge could be used in the design of prosthetic limbs such as running blades.

! Find out what materials are used for modern prosthetics such as running blades. What new possibilities do the carbon materials you investigated present? How might this affect the performance of para-athletes in sporting competition?

! You might find the following TED Talks of interest:

hugh_herr_the_new_bionics_that_let_us_run_climb_and_dance

aimee_mullins_prosthetic_aesthetics

dean_kamen_previews_a_new_prosthetic_arm

! Organize an assembly or school meeting to raise awareness of the achievement of para-athletes and Paralympians.

! Find out if any para-athletes might be prepared to speak at your assembly or meet fellow MYP students. Present your findings about new materials and prosthetic limb design.

! Livecast (stream online video) your assembly/event so that people can watch it wherever they are – perhaps family in other countries or students in another school.

SOME REVIEW PROBLEMS TO TRY

1 a **State** the names of the following compounds:

i SiO_2

ii KCl

iii NaN_3

iv SO_3.

b **State** which compounds show ionic bonding and which covalent, **outlining** your reasoning.

c **Describe** in terms of electrons what happens when silicon atoms meet oxygen atoms, and when potassium atoms meet chlorine atoms. You may answer this question using an annotated diagram if you prefer.

d **Define** what a metallic bond is and **describe** how it is formed.

e **Identify** one property that you would expect a metallic substance to have, **explaining** it with reference to the type of bonding present. Do the same for an ionic substance and a simple covalent substance.

f Diamond and graphite are allotropes of carbon. **Explain** how the bonding in each has an effect on the ability to conduct electricity and on how hard the substances are.

2 You are an architect who has been commissioned to design a footbridge across a scenic river in a forest. Your client wants a bridge that is simple and elegant in design, and that uses only natural materials such as wood. The river is 25 m wide. You decide to build a bridge using two triangular truss structures like this:

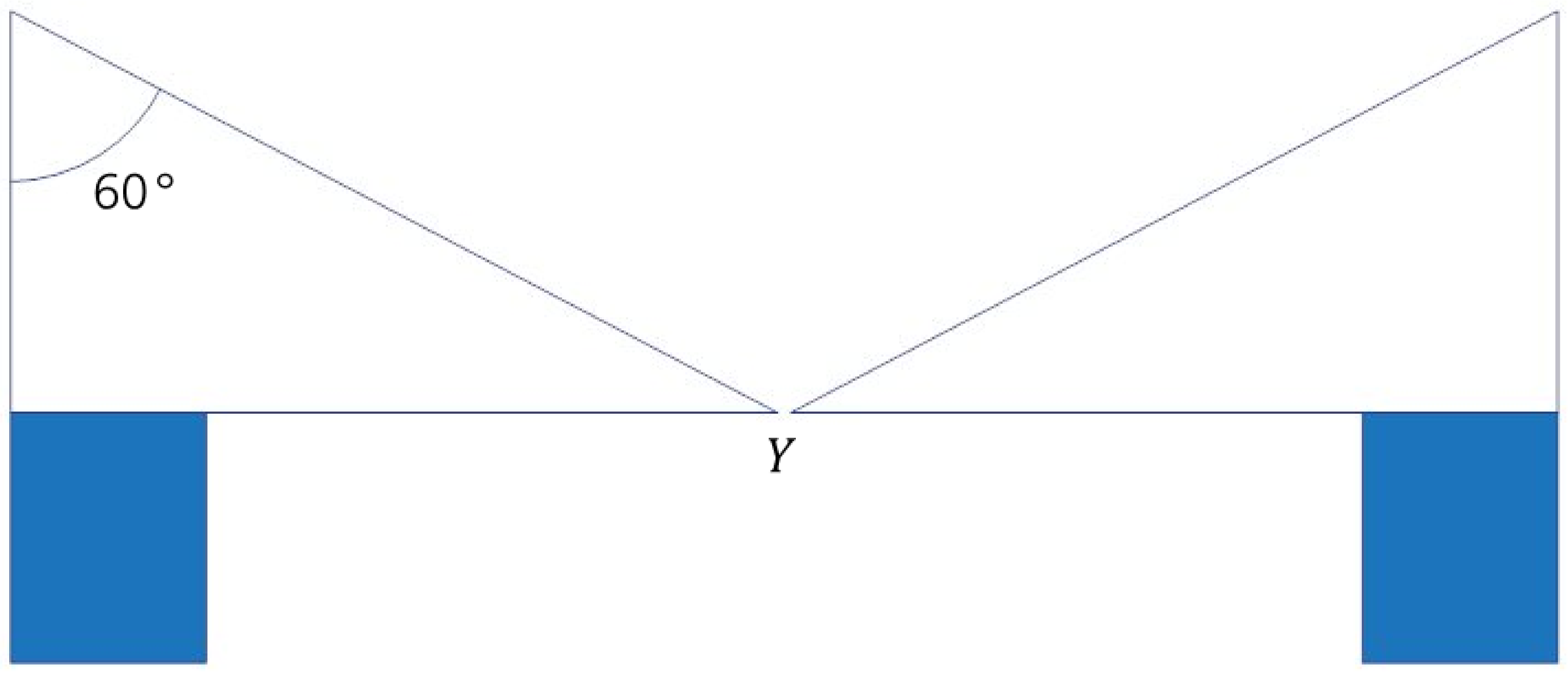


Figure 4.36

- **a** Using one of the bridge simulators mentioned earlier in the chapter, **deduce** whether the bridge design will work.
- **b** One angle in the truss is 60° as shown. **Show** the other angles that form one of the triangular trusses.

Look at Table 4.4 which gives the properties of some different building materials you can use for the bridge.

Material of beam (0.1 m × 0.1 m)	Maximum load TENSION/kN	Maximum load shear BENDING/kN
pine	82.7	99.2
Douglas fir	117.0	115.0
oak	79.3	111.0

■ **Table 4.4** Properties of building materials

- **c** **Analyse** the information in the table. **State** which wood you would use for the bridge structure and **explain** your reasons.
- **d** Using the values for your chosen wood, **calculate** the maximum load the bridge could support at the centre (Y).
- **e** Unfortunately, a mistake is made when ordering the beams. They have all been cut in the wrong direction and this means that their bending strength is, in fact, only 75 per cent of what was expected. There is no money left in the budget to buy new materials! **Evaluate** how this fact will affect the strength of the bridge. **Summarize** (without calculating) how you might change the design so that the bridge will remain as strong as before, using the wood you have available.

Reflection

In this chapter we have **explained** the different ways that atoms can bond to each other and **explained** how the properties of these structures are the result of the bonding present. We have learnt how to **deduce** the names of ionic and covalent compounds and **formulate** word and balanced symbol equations with state symbols for a range of chemical reactions. We have **described** how the element carbon can take on different physical forms, each with its own special properties and **described** how creating alloys can change the properties of metals, widening their scope of use. We have **analysed** systems of force to understand how they might balance or produce deformation and we have **applied** this understanding to artificial and natural structures.

<table>
<tr><th colspan="6">Use this table to reflect on your own learning in this chapter</th></tr>
<tr><td>Questions we asked</td><td>Answers we found</td><td colspan="4">Any further questions now?</td></tr>
<tr><td>Factual</td><td></td><td colspan="4"></td></tr>
<tr><td>Conceptual</td><td></td><td colspan="4"></td></tr>
<tr><td>Debatable</td><td></td><td colspan="4"></td></tr>
<tr><td rowspan="2">Approaches to learning you used in this chapter</td><td rowspan="2">Description – what new skills did you learn?</td><td colspan="4">How well did you master the skills?</td></tr>
<tr><td>Novice</td><td>Learner</td><td>Practitioner</td><td>Expert</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Learner profile attribute(s)</td><td colspan="5">Reflect on the importance of being knowledgeable for your learning in this chapter</td></tr>
<tr><td>Knowledgeable</td><td colspan="5"></td></tr>
</table>

5 How do we obtain the energy we need?

Nature provides the **energy** we need and we should seek to use it by **changing** its form in ways that are **sustainable**.

KEY WORDS

activation	form	product
conservation	level	reaction
conserve	process	transfer

CONSIDER THESE QUESTIONS:

Factual: What are the properties of states of matter? Where does our energy come from? How do we use energy for motion? What are enzymes and what is their role in cellular metabolism?

Conceptual: What is energy and what forms can it take? How are force and energy related? How do enzymes improve our lives? How does energy get transferred and transformed in living things? How do organisms depend on what they exchange with their environment?

Debatable: Does nature ever waste energy?

Now **share and compare** your thoughts and ideas with your partner or with the whole class.

IN THIS CHAPTER, WE WILL …

- **Find out** how the concept of energy can be used to explain the processes we observe in nature.
- **Explore** how humans have learnt from these processes in order to make machines and solve problems.
- **Take action** to apply understanding of energy processes in order to solve problems in more efficient, sustainable ways.

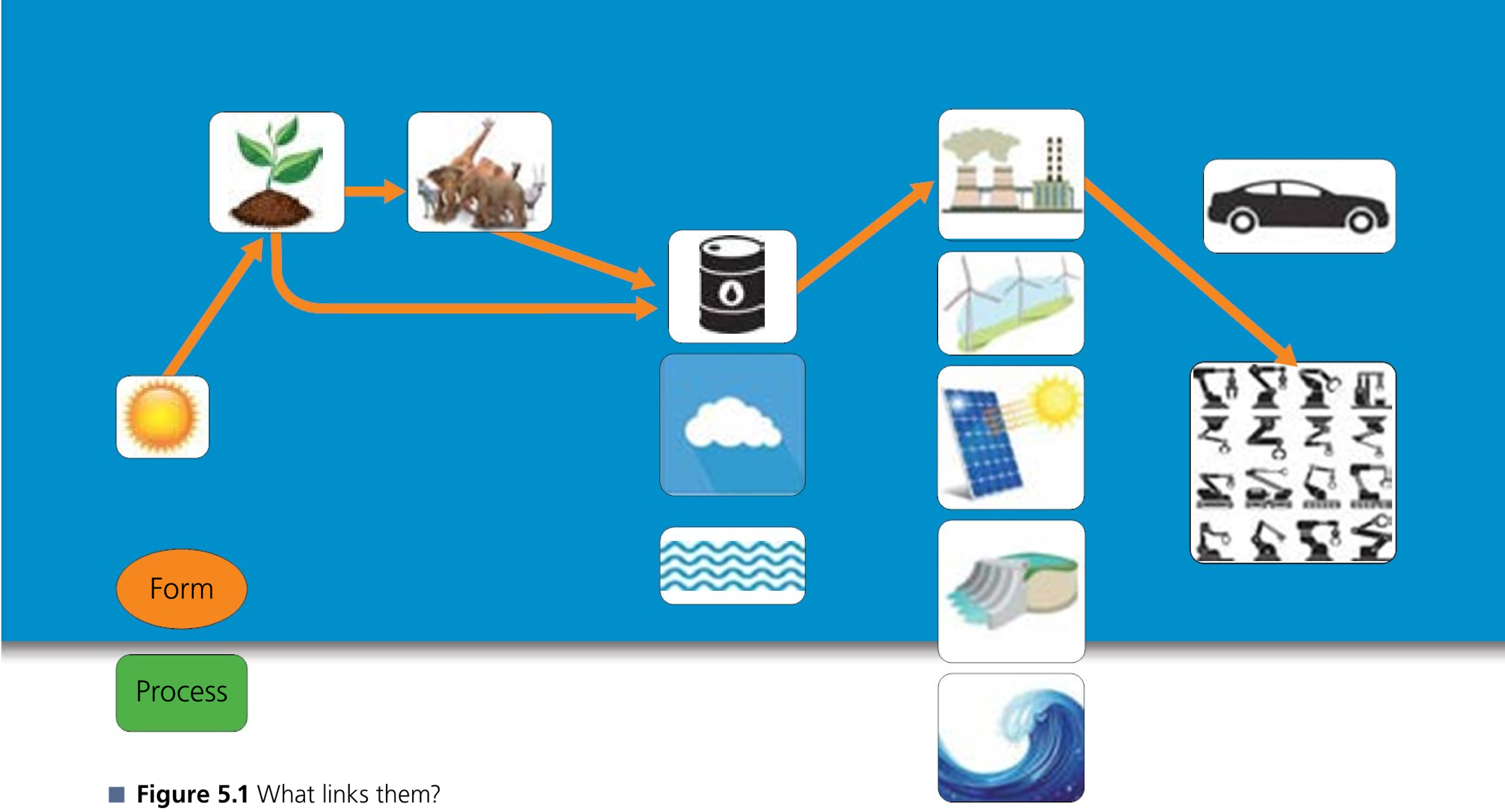
These Approaches to Learning (ATL) skills will be useful …

- Information literacy skills
- Organization skills
- Collaboration skills
- Critical-thinking skills
- Transfer skills
- Communication skills
- Reflection skills
- Creative-thinking skills

Assessment opportunities in this chapter:

The activities in this chapter will help you develop and evaluate your learning in these MYP Sciences learning objectives:

- **Criterion A:** Knowing and understanding
- **Criterion B:** Inquiring and designing
- **Criterion C:** Processing and evaluating
- **Criterion D:** Reflecting on the impacts of science



■ **Figure 5.1** What links them?

We will reflect on this learner profile attribute …

- Knowledgeable – we will use our conceptual understanding of energy to inquire in different contexts.

CONNECT–CLASSIFY–ELABORATE

Look at the images in Figure 5.1 What do you think they represent? Some connections are shown. How else might they be connected?

In this topic we will explore and elaborate the connections between these things in different ways and from the perspectives of different sciences.

Energy is the concept we use to explain why change happens. There is an old expression that occurs in many languages: there is no constant in the Universe other than change. Some changes can be **reversible**, because we can take whatever is produced and then return it to its original components or state. But many of the changes on which humanity relies are **irreversible**, because once they're done, they can't be undone.

We could, for example, connect some of the boxes as shown in Figure 5.1.

These arrows might represent the flow of energy through a system. Notice that the arrows point in one direction, so the energy only flows in one direction. The energy of the Sun is captured and stored in plants, animals feed on plants, both plants and animals were converted into fossil fuels in geological time, and so on until we arrive at an endpoint: machines made by humans to exploit and utilize the energy.

We might consider the form that the energy takes at each of these stages and also the processes that cause the energy to change form.

In an irreversible process, the energy is transformed into a form that cannot be recouped or stored for later use. The final form of this energy is **thermal energy** that is transferred as heat from one body to another or dissipated away into space and lost entirely. In fact, we will see later that some energy is lost in this way in *all* processes.

ACTIVITY: Thinking about energy change, forms and processes

ATL

- Organization skills: Use appropriate strategies for organizing complex information

As you explore the different kinds of energy changes in this chapter, make a note of the forms that the energy takes. Consider the processes that are described here. Complete your own version of the energy-flow diagram in Figure 5.1, elaborating the connections between things as *forms* and *processes.* Notice too how the different sciences provide different perspectives on different parts of the energy flow.

In *MYP Sciences by Concept:* Books 1 to 3, we considered energy changes in many different contexts and looked at some of the processes that bring it about. Before we begin our deeper inquiry in this chapter, you might wish to review what you already know about energy forms and types. Use one of the visual organizers described in the box on the right to collect your class ideas about the words and phrases in this list:

- energy types
- energy forms
- energy sources
- energy laws
- energy impacts

Brainstorms, mindmaps and visual Venns

Brainstorming is a way to think creatively, whether individually or in groups. The idea is that you start with a key concept or idea and then write down anything that occurs to you in relation to that concept or idea. The only rules are: don't keep ideas to yourself and don't 'block' or judge other people's ideas. For more information, try online resources such as: **www.mindtools.com/brainstm.html**

Visual Venns are an adaptation of Venn diagrams, as used in logic and mathematics. Venn diagrams are a visual representation of the way that items are grouped by shared characteristics. Where items in a group share some properties with items in another group, the Venn circles overlap (see *MYP Sciences by Concept 1:* Chapter 6 for an example). Visual Venns can help you sort and organize ideas, without necessarily structuring them.

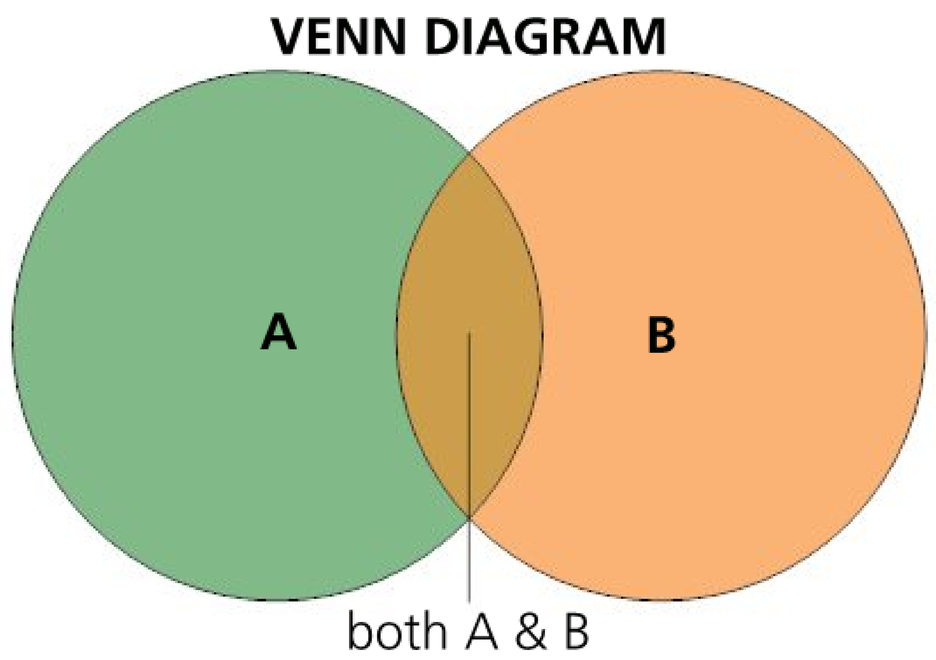


Figure 5.2 Visual Venn diagram

Mindmapping is a tool for structuring ideas. Again, start with a central concept or idea – it often works best to represent this as an icon or image of some kind. 'Branches' out from the central idea introduce related concepts or ideas that are perhaps subsidiary to (less important, but related to) the central idea. You can then break these branches down again into 'twigs'. Mindmapping takes you from a big picture to details in a structured way and can be a good way to organize arguments. Find out more by searching **mindmapping** online.

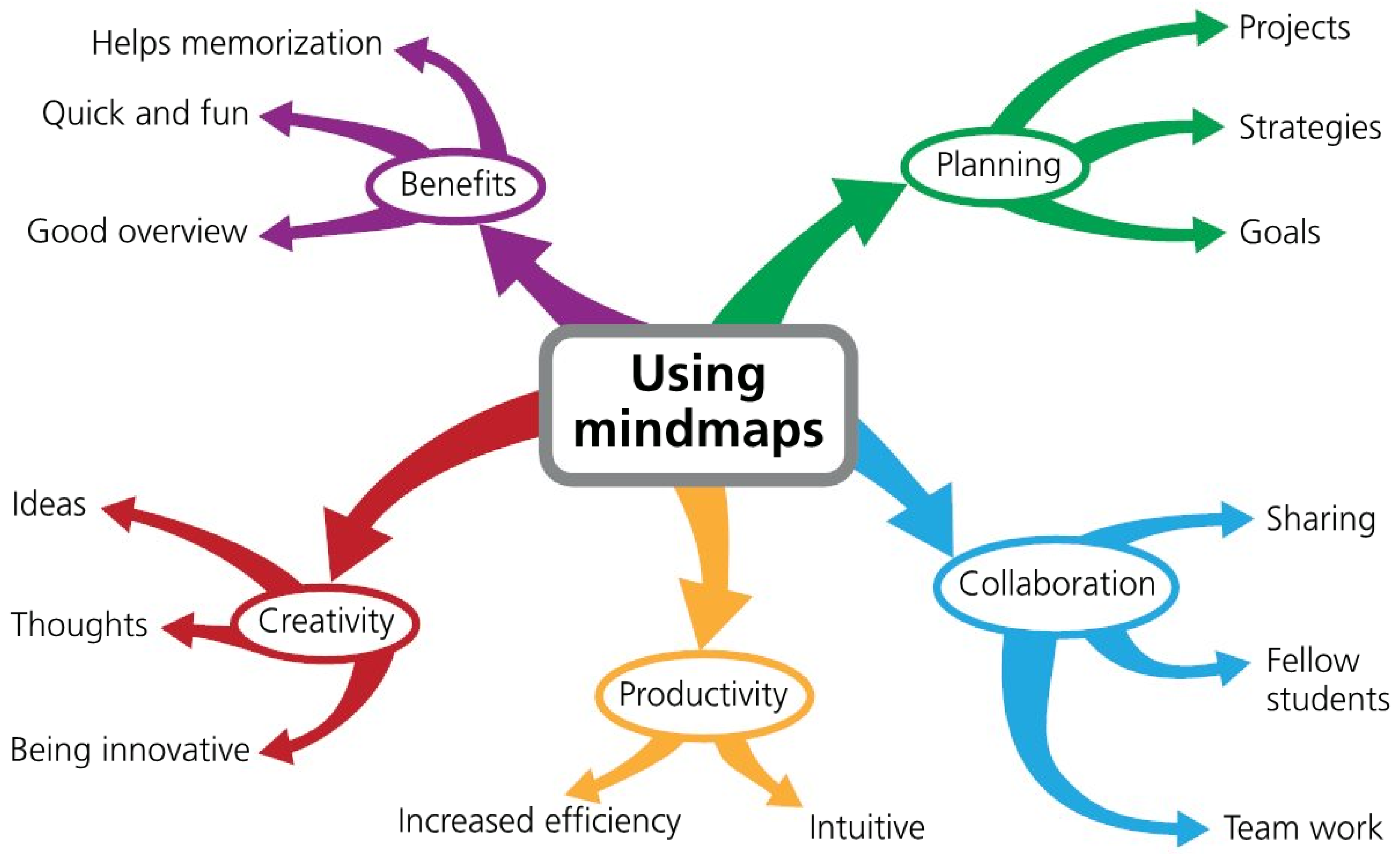


Figure 5.3 Mindmapping

What is energy and what forms can it take? What are the properties of states of matter?

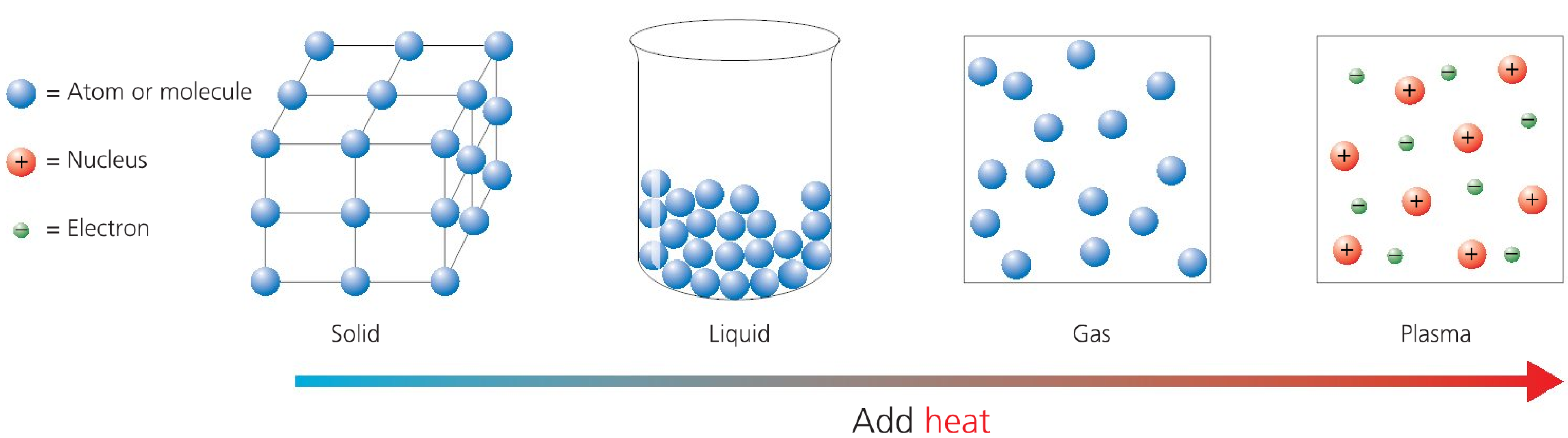
You may know from previous learning that energy can be **classified** according to the form it takes. You will probably know the names of many of these forms (Figure 5.4).

However there is a more general way to classify energy, which you may have encountered in *MYP Sciences by Concept Book 1* or *3*. We also discussed in Chapter 4 how energy can be stored in chemical bonds or be present in the motion of atoms within a material.

Where energy is causing motion, we describe it as kinetic energy. Where energy is present, but stored in some way, we call it potential energy. In the case of a melting ice lolly, we could perhaps see the kinetic energy in the ice slipping down your hand, but there is motion too in the particles which make up the ice. This particle motion is the thermal energy contained in the particles. When thermal energy is transferred from the warm environment of a hot summer day to the ice particles, their kinetic energy is increased. The increased kinetic energy of the particles allows an increasing number of the particles to first loosen and then to escape the physical forces that hold them in the frozen ice and the ice changes state to liquid water. A change of **physical state** occurs (see *MYP Sciences by Concept 1:* Chapter 2).

Similarly, the motion in the torch in Figure 5.4(b) is that of the electrons moving through the circuit to produce heat and light energy in the bulb (see Chapter 8).

■ **Figure 5.4** Forms of energy: (a) vibrating string, (b) torch, (c) atom



■ **Figure 5.5** Changes of physical state

ACTIVITY: Heat it up

ATL

- Communication skills: Make inferences and draw conclusions
- Transfer skills: Apply skills and knowledge in unfamiliar situations; Combine knowledge, understanding and skills to create products or solutions

Figure 5.6 shows a generic heating curve. Temperature, which is shown on the y-axis, is a measure of the average kinetic energy of the particles.

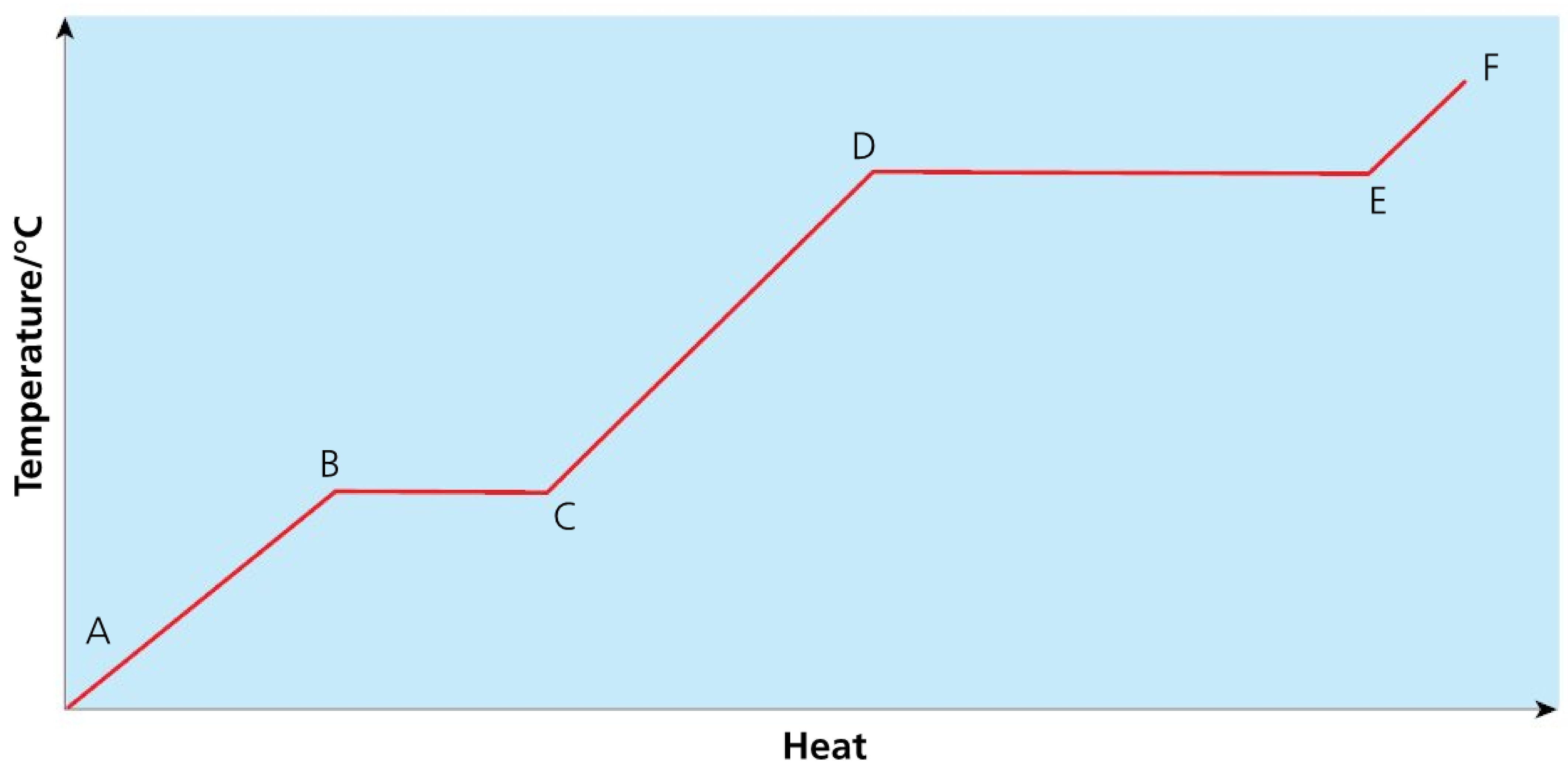


Figure 5.6 A heating curve

A heating curve is characterized by one or two plateaux (flat areas) where heat energy added to the substance (increase in value of x-axis) does not result in an increase in temperature (on the y-axis). This is because, at this point, all of the heat energy going into the system is used for breaking the bonds between the particles and increasing the potential energy stored in the bonds rather than increasing the kinetic energy of the particles. The plateau, therefore, indicates a change of state and the temperature at which the plateau occurs is the melting/boiling point. By breaking the bonds, the particles are able to move further apart, which leads to **thermal expansion**.

Use the information here and your knowledge of the kinetic theory of particles to complete the following tasks:

1. **Identify** the states at positions A–B, C–D, E–F.
2. **Deduce** what transition process is happening at B–C and D–E.
3. **Explain** how changes of state happen using the kinetic theory of particles.
4. **Sketch** a heating curve for water considering all of its changes of state, making sure you include the relevant temperature values on the y-axis.
5. A cooling curve is the opposite of a heating curve, whereby the temperature of the particles decreases as heat energy decreases. **Sketch** a cooling curve for pentane (boiling point = 36 °C, melting point = –130 °C). Use particle theory to **explain** what is happening at one of the changes of state.
6. **Explain** how even a very slight increase in temperature can be measured by a liquid thermometer, using kinetic theory of particles.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

EXTENSION

When our body temperature increases, we produce sweat to cool us down.

Explain, using kinetic theory, why you cool down when you sweat (you may find *MYP Physics by Concept 4&5:* Chapter 6 helpful here).

ACTIVITY: The fast and the furious

ATL

- Critical-thinking skills: Draw reasonable conclusions and generalizations; Revise understanding based on new information and evidence; Evaluate evidence and arguments; Interpret data; Practise observing carefully in order to recognize problems

How many times have you wandered into the kitchen to find out what smells so good? The reason you can smell foods from different rooms is because gaseous particles released by the food travel by a process called diffusion. Diffusion is defined as the movement of particles from an area of high concentration to an area of low concentration, until they are evenly spread.

Your teacher will demonstrate a chemical reaction between diffused hydrogen chloride and ammonia gas to form ammonium chloride.

Safety: Concentrated hydrochloric acid and concentrated ammonia solutions are both corrosive, while concentrated ammonia solution is also dangerous for the environment. The demonstrator should wear protective gloves and safety goggles and the experiment should be carried out in a fume cupboard due to the toxic nature of both hydrogen chloride gas (also corrosive) and ammonia gas which are produced by the concentrated solutions. During hot weather, pressure can build up in the bottle of concentrated ammonia, so this should be opened with care. The tube used must be clean and dry; a few drops of acetone (flammable) soaked in cotton wool can be used for cleaning. Students should wear safety goggles.

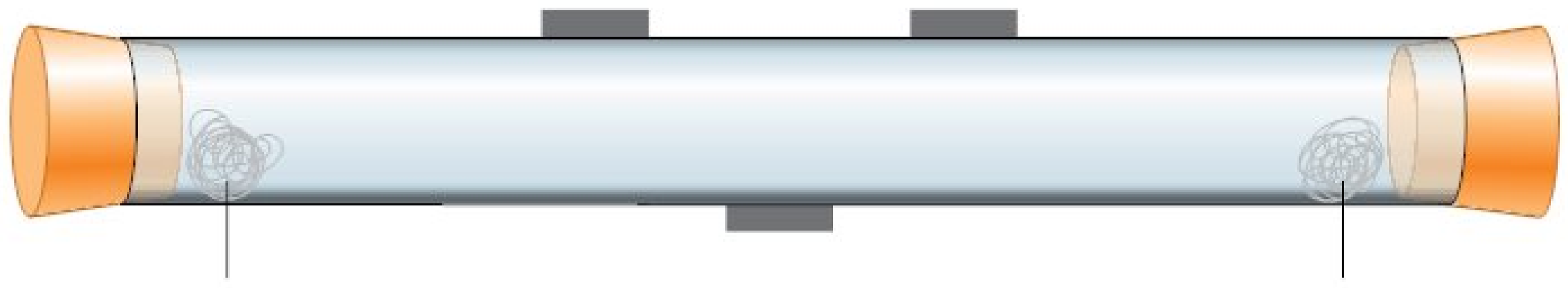


Figure 5.7 Observing the reaction between two diffusing gases

Analysis

1 **Draw an annotated diagram in your book of the demonstration. Use bullet points around your diagram to describe briefly the method for carrying out the investigation.**
2 **Identify any safety precautions that were taken by the person demonstrating the experiment, explaining why they were necessary.**
3 **Describe your observations as the reaction progressed.**
4 **Formulate a word equation for the reaction.**
5 **Measure the distance between the reaction product and each soaked piece of cotton wool. What can you deduce about the rate of diffusion of each reactant?**
6 **Suggest some factors that could affect the rate of diffusion of a substance.**
7 **Calculate the mass of hydrogen chloride (HCl) and ammonia (NH_3).**
8 **Draw a conclusion about the factors that may have affected the rates of diffusion in this experiment.**
9 **Evaluate the validity of the method.**
10 **Predict in which state diffusion is faster, supporting your prediction with scientific reasoning (kinetic theory).**
11 **Suggest whether solid substances are able to diffuse, supporting your suggestion with scientific reasoning (kinetic theory).**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding and Criterion C: Processing and evaluating.

EXPLANATION GAME

Do some research to find out about how impurities affect the boiling and melting points of pure substances. Use your findings to try to explain the following:

I notice that grit (salt) is thrown onto the roads during winter. Why is this done?

I notice that salt is sometimes added to the water used to cook an egg. Why is this done?

How are force and energy related?

■ **Figure 5.8** Frictional heating in action

WHAT MAKES YOU SAY THAT?

What is the energy change that you see in Figure 5.8? What makes you say that?

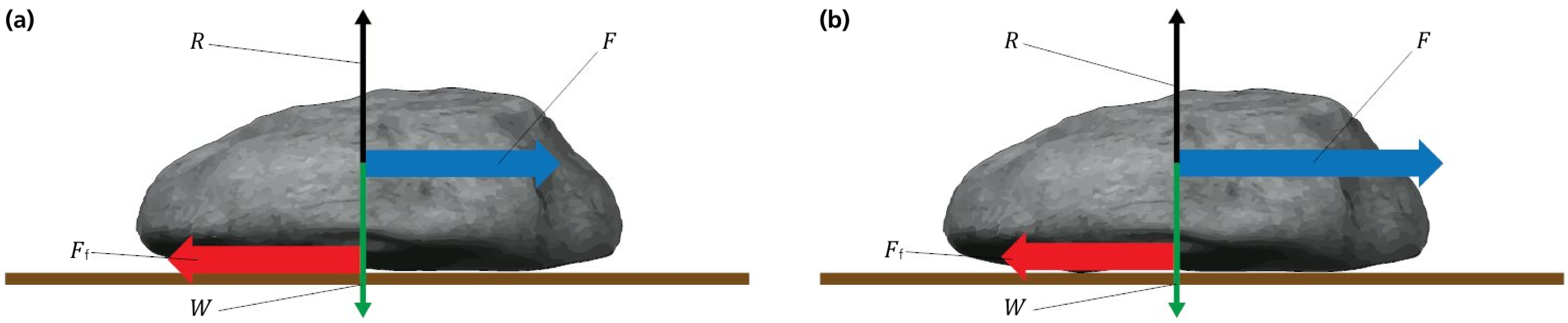
On a cold day you might rub your hands together to generate heat. Similarly, machine parts that move against each other quickly become very hot. This effect is caused by the force of friction. When two objects rub together, the force of friction causes the kinetic energy of their motion to be converted into heat.

The force of friction depends on the force with which surfaces push together and on the reaction forces of one surface on another. If an object is on a flat surface, friction is equal to:

$$F_f = \mu R$$

where F_f is the force of friction (N), R is the reaction force and μ (the Greek letter mu) is a coefficient (number) that describes the frictional properties of the surface.

The connection between motion and heat was observed by James Prescott Joule (1818–89). He was inspired by the industrial process of cannon boring. The cannon were made using large, solid bars of bronze or iron which were then 'bored' to make a hole through the centre. The boring equipment had to be cooled continually with water to remove the great heat generated.



■ **Figure 5.9** Friction acts against motion: (a) static friction opposes an accelerating force; (b) sliding friction

MEET A SCIENTIST: JAMES PRESCOTT JOULE

James Joule was one of the last in a line of 'amateur scientists'. His day job was as a brewer of beer and he had no formal education, having been schooled at home. But he did receive tuition from the chemist John Dalton (see Chapter 2) and Joule was born at a time and in a place that was fizzing with new ideas about the way the world worked. Joule's amateur status meant that the 'gentleman scientists' of the day were often sceptical about his findings but his idea about the relationship between heat and work finally caused the **paradigm shift** in physics that consigned to the garbage heap of history the idea that heat was a liquid called 'caloric'. Through willingness to **risk** rejection, through curiosity, perseverance and hard work, Joule was recognized as one of the most **knowledgeable** scientists of his age.

■ **Figure 5.10** James Prescott Joule

Try this online simulation to look at the way that work can be transformed into different kinds of energy (requires Java): **https://phet.colorado.edu/en/simulation/energy-forms-and-changes**

Joule conceptualized the idea of energy that is transformed to a useful end as 'work done'. By making a connection to force, he could show that

work done = energy changed = force × distance moved

or

$$W = \Delta E = Fs$$

where work done or energy changed ($W/\Delta E$) are measured in **joules** (J), force F is in Newtons (N) and distance s is in metres (m).

Notice that in Joule's equation it is assumed that no energy is lost. This is a statement of a fundamental principle of science: the **Principle of conservation of energy** which can be stated in this way:

The sum total of energy in a system remains constant provided no energy passes in or out of the system.

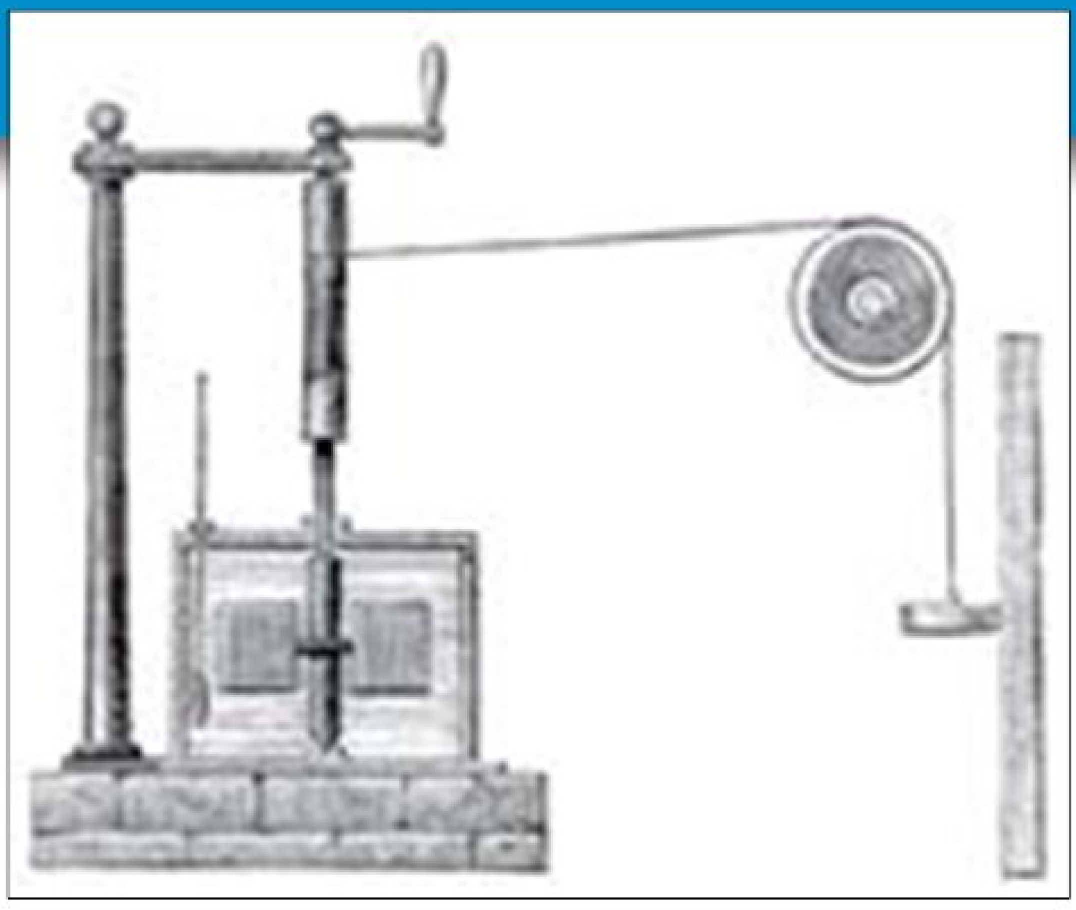
The 'system' here is the particular process. If we instead consider the system to be the entire Universe, then the principle of conservation of energy tells us that the sum total of the energy in the Universe always remains the same. In this case the principle is often given as 'energy is never created or destroyed'.

■ **Figure 5.11** Comparison of temperature and heat of 1 kg of water and a sparkler

EXTENSION

Equations of motion are used to describe the way that objects move (see Chapter 7). Using only two equations, **show** that the kinetic energy gained by a moving object that starts from rest (no initial velocity) is given by

$$\text{KE} = \frac{1}{2}mv^2$$



■ **Figure 5.12** Joule's experiment to demonstrate the equivalence of work and heat

HEAT MATTERS

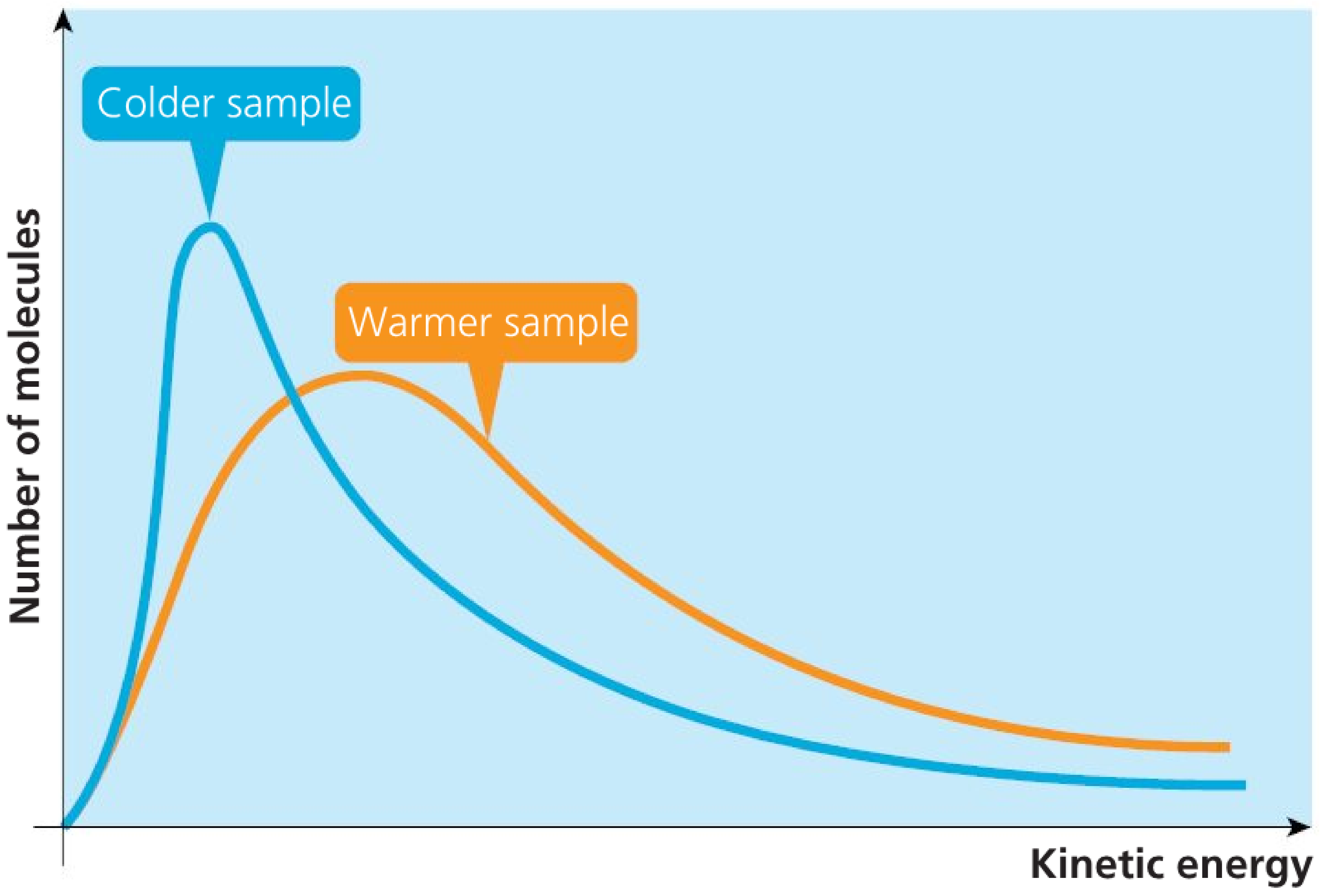
Although we might not think of everything as being 'hot', everything – as far as we know – contains energy that can be transferred as heat. We tend to judge the 'hotness' of things by to how they feel, which depends on the temperature of our own bodies – on average, 37 °C. The amount of energy that is transferred between objects at different temperatures is given the symbol Q, while temperature is given the symbol T.

Heat (Q) is the *total energy* transferred between two objects at different temperatures in the form of kinetic energy.

Temperature (T) is a measure of the *average kinetic energy* of the particles in an object.

A white hot metal 'spark' has a temperature near to 2000 °C. A kettle of boiling water has a temperature of 100 °C. Which of the two would be most dangerous in contact with your hand?

Although the spark is 'white hot', its mass is tiny, perhaps 0.01 g at most, so it contains relatively little heat energy and might only feel like a pin-prick on your hand. Conversely, a 1 litre kettle of boiling water contains enough energy to seriously damage you and should never be poured over skin. The amount of heat is a *total* for all the particles and the number of particles depends on the *mass* of the object. The temperature, however, does *not* depend on the mass because it is an average of all particles (Figure 5.13).



■ **Figure 5.13** Graph showing the number of particles with different kinetic energies in a given mass. Note that because temperature measures the average kinetic energy in the mass, some particles will have more than this energy and some will have less. The *total* heat is the sum of all the energies under the curve.

Theoretically, there *is* a temperature where none of the particles are moving; the substance has zero thermal energy. This temperature is called **absolute zero**. The Celsius temperature scale is designed with reference to the freezing point (0 °C) and boiling point (100 °C) of water, but scientists often use the absolute or Kelvin temperature scale instead, where

0 K = –273 °C

In fact, the Kelvin is the SI base unit for temperature since it is defined relative to this absolute point; however temperature changes are the same on both scales, since 1 °C = 1 K.

ACTIVITY: Measuring red heat

ATL

- Information literacy skills: Collect, record and verify data; Process data and report results
- Critical-thinking skills: Practise observing carefully in order to recognize problems; Draw reasonable conclusions; Evaluate evidence and arguments

Safety: In this experiment you will be heating metal objects to very high temperatures. Wear safety glasses and use heat-protective equipment as given at all times. Follow laboratory safety rules with close attention, particularly ensuring that loose hair and clothing are tied safely.

Inquiry: How can we measure the temperature of something too hot to measure directly?

You may recall from *MYP Sciences by Concept 1:* Chapter 4 that when we increase the temperature of an object, it re-emits thermal energy by **radiation**. We will look at the nature of colour and light in Chapter 10.

In this experiment you will use the technique of **calorimetry** and what you know about the relationship of thermal energy Q and temperature T to **measure** the temperature of a red-hot object indirectly.

Background

Summarize what you already know about the relationship between thermal energy Q and temperature T for an object.

Equipment

- **Metal bar**
- **Beaker (50–250 cm^3, depending on mass and size of bar)**
- **Digital temperature sensor and datalogging equipment**
- **Polystyrene or similar lid for beaker with hole for the thermometer**
- **If available, polystyrene or similar insulation for the beaker**

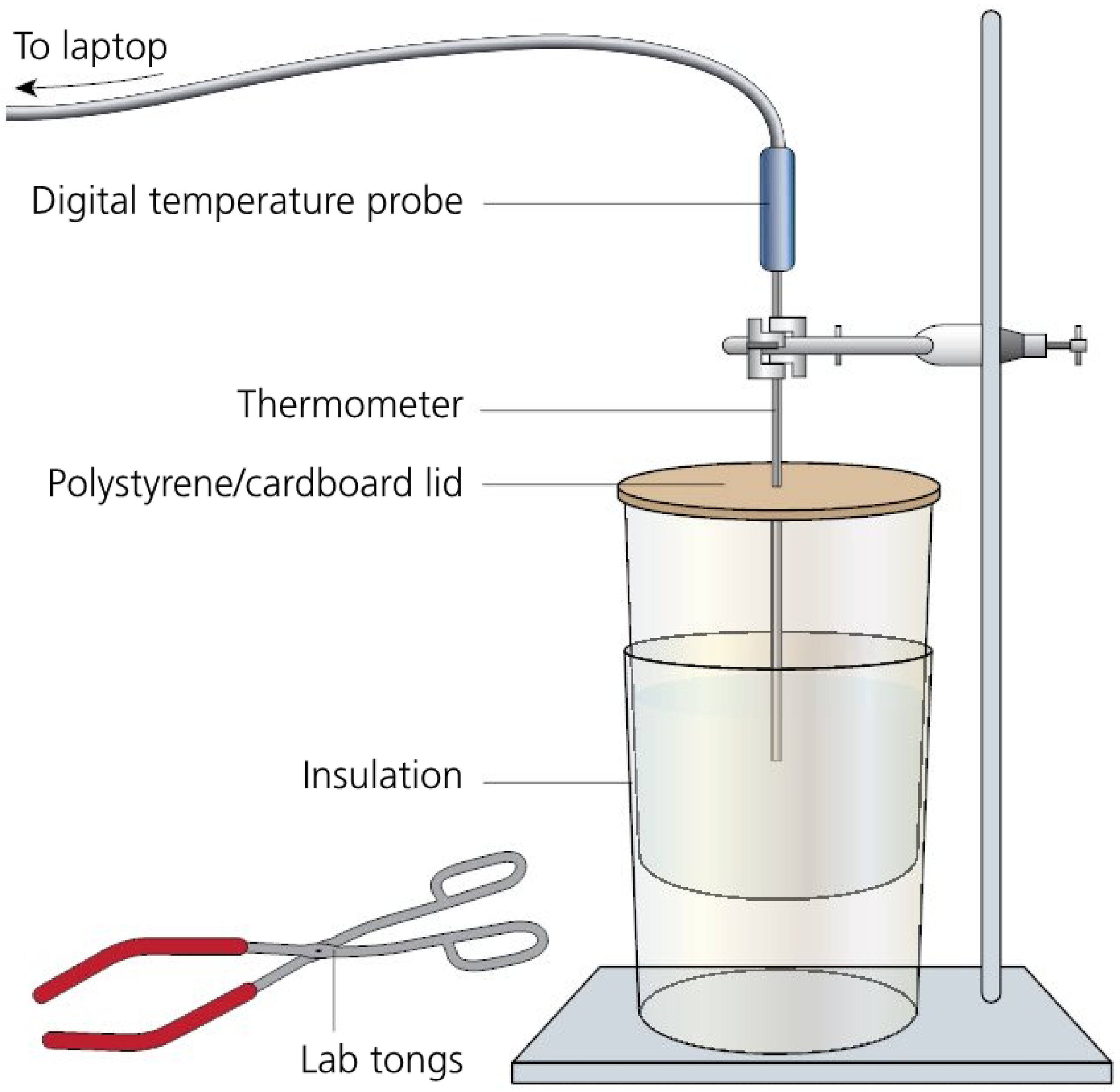


Figure 5.14 Experiment set-up for measuring red heat

Discuss

Before you begin, **discuss** with your partner why the insulation is going to be important.

Method

1. **Prepare your calorimetry equipment as shown in Figure 5.14. Ask your teacher to check that you have followed safety rules carefully before you begin.**
2. **Measure the mass of the beaker alone or place it on the balance and press 'Tare'.**
3. **Pour sufficient water into the beaker such that it will cover the metal bar completely when it is placed in the beaker.**
4. **Now measure the mass of water in the beaker.**
5. **Measure the mass of the metal bar.**
6. **Use a Bunsen burner or other heater to heat the object until it begins to glow red.**
7. **Place the temperature sensor in the water. Start the datalogger.**
8. **While one person lifts the lid of the beaker, the other moves the metal bar using safety tongs and places it into the water. Care! There is likely to be some boiling and spitting of water.**
9. **Replace the lid (and insulation as appropriate).**

Analysis

Present the datalogger data in a suitable form.

Interpret your data. **Summarize** the temperature changes you observed in the water. **Estimate** the highest temperature the water reaches during the experiment.

The law of conservation of energy tells us that thermal energy in the metal bar will **conduct** to the water when they are placed together.

Write down an equation which relates the thermal energy of bar and water to the temperature change in each.

Search online to find the specific heat capacity of your metal.

Hint

Use the equation $\Delta Q = mc\Delta T$ twice, noting that:

- the mass of water and mass of bar will not be the same
- the specific heat capacity of the metal bar and the water will not be the same.

We can rewrite $\Delta T = (T_2 - T_1)$ where T_2 and T_1 are the end and initial temperatures of the bar and the water, respectively.

Solve the equation you have written to find the initial temperature T_1 for the metal bar.

Evaluate the validity of your experiment. What assumption did we make? How **valid** was that assumption? Was anything else happening in the water when you placed the metal inside? **Explain** how you could improve either the experiment method or your method of analysis to account for this problem.

Assessment opportunities

In this activity, you have practised skills that are assessed using Criterion C: Processing and evaluating.

EXTENSION

Some school laboratories have **infrared** temperature sensors that can measure the temperature of an object directly from the radiation it emits. If your school has one of these, use it to measure the temperature of the red-hot metal bar. **Compare** to your answer from the calorimetry method. Which do you think was the most accurate?

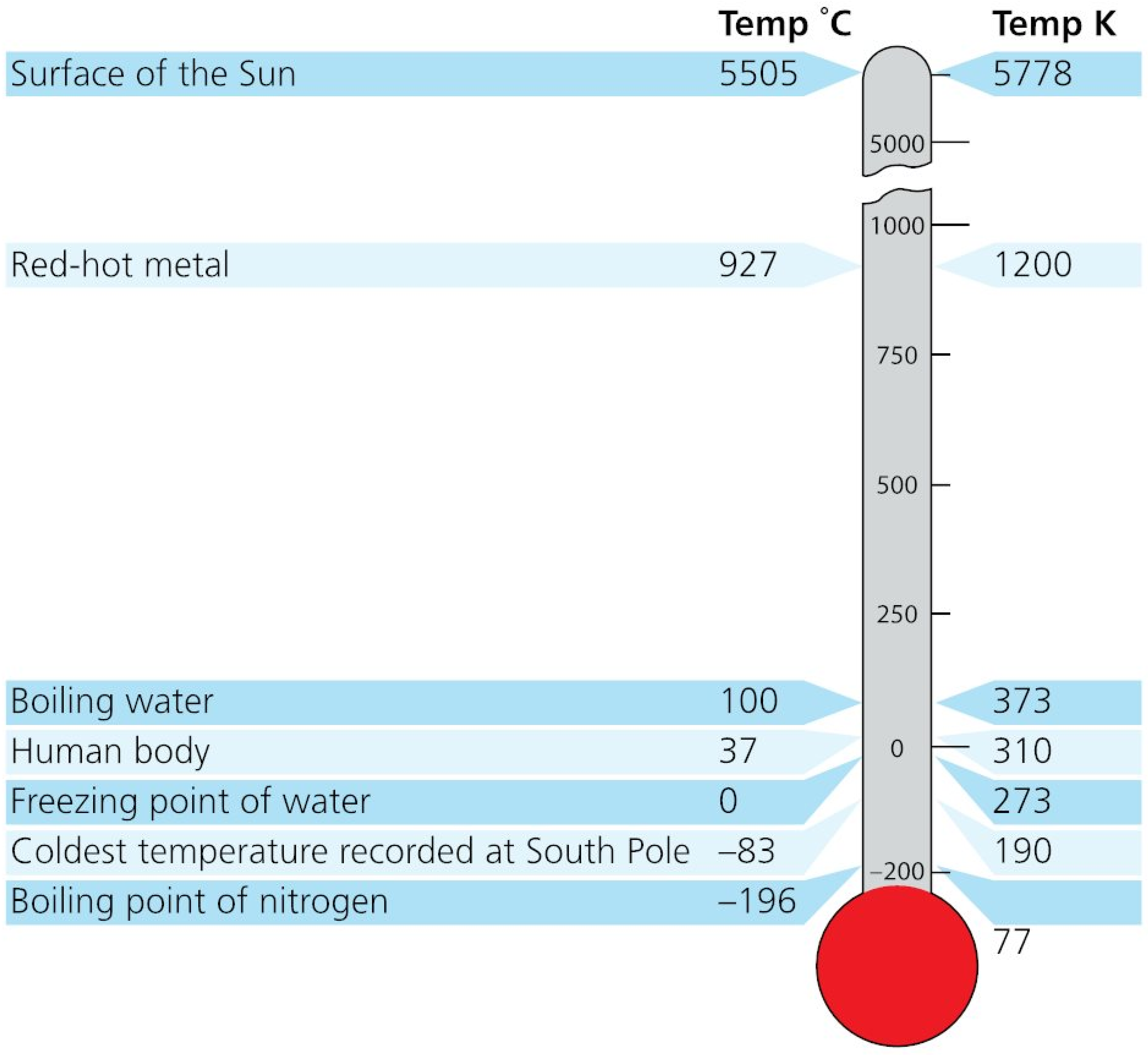


Figure 5.15 Comparison of temperatures on the centigrade and Kelvin scales

Where does our energy come from?

SEE–THINK–WONDER

Look at Figure 5.16. What do you **see**? What do you **think** about that? What does it make you **wonder**?

■ **Figure 5.16**

The images in Figure 5.16 are all examples of fuels. Fuels, by undergoing chemical reactions, provide us with the energy we need to stay alive, produce electricity and travel.

Fuels contain chemical energy, a type of energy stored in the bonds of atoms and molecules. We get the energy we need to stay alive from the chemical energy stored in our food (our fuel), which is released through the biological processes of digestion and the chemical reactions of respiration (see later this chapter). The energy we need for transport and to generate electricity is stored as chemical energy in fossil fuels and is released by a type of chemical reaction called combustion.

EXTENSION

Apply what you have learnt in the box below to suggest what type of reactions feature in the activities *Writing word equations* and *Balance away* in Chapter 4.

GENERATE–SORT–CONNECT–ELABORATE

Generate a list of ideas and initial thoughts that come to mind when you think about the term 'chemical reaction'. Write down each thought/idea on a separate sticky note; it could be a single word, an example of a chemical reaction you know or have seen in class, or a descriptive sentence.

Form groups of three or four, bringing all your sticky notes with you. Each group will also be provided with an A1 sheet of paper (or you can make your own by taping eight A4 sheets together). You will now be provided with some information to help you sort your ideas. Chemical reactions are separated into four broad categories: **synthesis**, combustion, displacement and decomposition reactions. Write these headings on four new sticky notes and stick the headings on your A1 sheet of paper, spreading them out as much as possible. Consider the words in contexts outside of science. What do they mean? Could they have the same meaning in a scientific context? Have you met them before in any other scientific topics? **Generate** new sticky notes with additional thoughts and ideas.

- **Sort** your sticky notes by placing them around these headings like the numbers on a clock. If some are relevant to more than one heading, create as many additional notes as necessary with the same information. Place the notes according to how central or tangential they are; for example, ideas that you know are central should be placed near the heading while more tangential ideas will go towards the outside of the 'clock'.
- **Connect** your ideas by drawing connecting lines between ideas that have something in common. You can draw lines between the sticky notes that have been duplicated. Explain and write in a short sentence how the ideas are connected.
- **Elaborate** on any of the ideas/thoughts you have written so far by adding new ideas that expand, extend or add to your initial ideas.

TYPES OF CHEMICAL REACTIONS

As there are so many different chemical reactions, grouping them together according to their type can help us better understand how the substance(s) are transformed. Nearly all chemical reactions result in an overall change of energy and most reactions are exothermic. You explored the terms exothermic and **endothermic** in *MYP Sciences by Concept 3:* Chapter 1. All reactions need energy to get started; some need so little that they are able to start at room temperature. Others may need a little help, which is often provided in the form of heat.

Figure 5.17 provides a bit more information about how chemical reactions are divided up and makes reference to where we met these types of reactions in previous chapters or will meet them later on.

TYPES OF CHEMICAL REACTIONS

SYNTHESIS (direct combination)

- Reactions where at least two reactants **combine** to form a more complex product.
- Link to Chapter 3: the group 1 metals left exposed to air **combined** with the oxygen to form a new single product, sodium oxide, at room temperature.
- Another example is magnesium burning in oxygen. Heat is needed to start the reaction, but once it gets going, large amounts of energy in the form of light and heat are released, making the reaction overall **exothermic**.
- **Photosynthesis**, explored later in Chapter 5, is a very important synthesis reaction.

COMBUSTION

- Reaction of a substance with **oxygen** that produces **energy**.
- Energy is often released in the form of **heat and light**. We rely on these reactions as sources of energy in our lives.
- The reaction of magnesium with oxygen is a **combustion** reaction as well as a **synthesis** reaction.

  All combustion reactions are oxidation reactions (Chapter 8) and **exothermic** reactions, making them very useful but also dangerous.

DECOMPOSITION

- The breakdown of a single reactant into multiple products.
- An example is the thermal decomposition of any metal carbonate into the metal oxide and carbon dioxide. Calcium carbonate decomposes to calcium oxide and carbon dioxide.
- Thermal means heat is needed and the reaction will not happen at room temperature. **Thermal decomposition** reactions are therefore **endothermic**.

DISPLACEMENT

- A reaction where a more reactive element takes the place of a less reactive element in a compound.
- Link to Chapter 3: the group 17 elements undergo displacement reactions when a more reactive halogen displaces a less reactive halogen in solution, taking its place.
- This is an example of a **single displacement reaction**. There are also **double displacement reactions** which include neutralization and precipitation reactions (explored in Chapter 6).

■ **Figure 5.17** Summary of the types of chemical reactions

ACTIVITY: Energy in or energy out?

ATL

- Critical-thinking skills: Interpret data; Draw reasonable conclusions and generalizations; Revise understanding based on new information and evidence

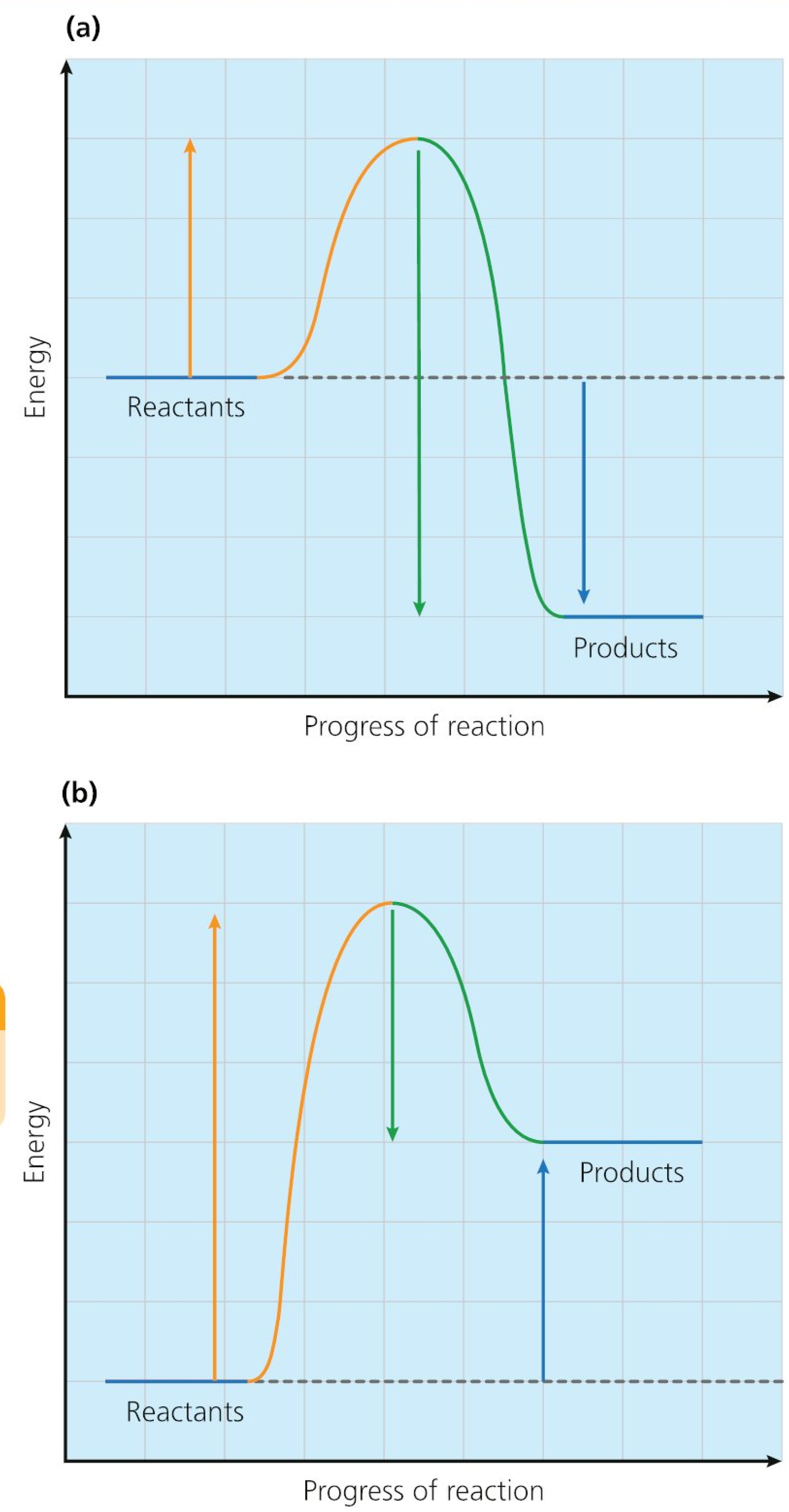
Combustion reactions are exothermic reactions. Can you **interpret** diagrams representing the energy changes in chemical reactions? Find out by answering the questions below.

1. **The diagrams in Figure 5.18 are called energy level diagrams or energy profile diagrams. They show the overall energy change for a chemical reaction. Describe the relative energies of the reactants and products in each diagram.**

Hint

Refer back to MYP Sciences by Concept 3: Chapter 1 for help interpreting energy level diagrams.

2. **Deduce which diagram represents an endothermic reaction and which represents an exothermic reaction.**
3. **Suggest what process could be happening that makes the energy of the system increase (orange part of the curve). Comment on what the orange arrows pointing upwards could, therefore, represent.**
4. **Suggest what process could be happening that makes the energy of the system decrease (green part of the curve). Comment on what the green arrows pointing downwards could, therefore, represent.**
5. **Comment on what the blue arrow pointing downwards in Figure 5.18a and the blue arrow pointing upwards in Figure 5.18b could represent.**
6. **Suggest a chemical reaction that each diagram could represent.**



■ **Figure 5.18** Energy profile diagrams for two different reactions

For an opportunity to investigate endothermic and exothermic reactions experimentally, refer to the activity *Heating up, cooling down* in *MYP Sciences by Concept 3:* Chapter 1.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

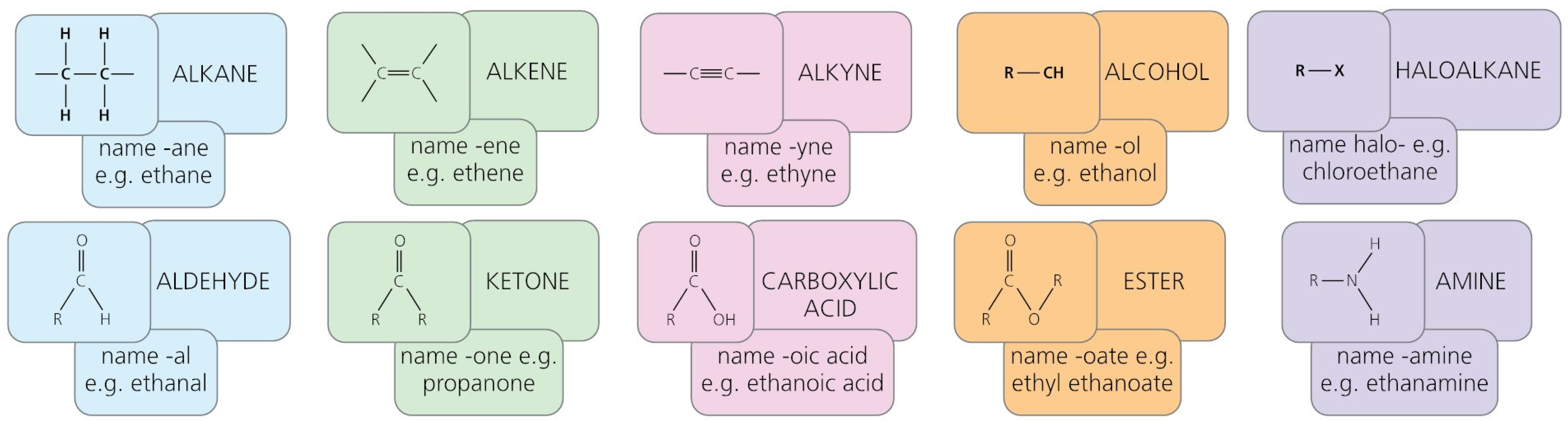


Figure 5.19 Each homologous series has a different functional group

WHAT MAKES YOU SAY THAT?

What kind of properties do you think a good fuel should have? What makes you say that?

DISCUSS

Can you work out the formula of the third alkane in the series that has three carbon atoms? **Explain** your answer.

THE COMBUSTION OF FUELS

Coal, crude oil and natural gas (mainly methane) are fossil fuels. They all contain carbon and most contain other elements as well. We explored some of the unique chemistry of carbon in Chapter 4. Another of carbon's specialities is an ability to form a huge variety of molecules.

The study of carbon-containing compounds is called **organic chemistry**. Organic compounds that have similar properties are grouped into families and called **homologous series**. Each homologous series is characterized by a **functional group**: an atom, group of atoms or type of bond that distinguishes it from other homologous series. Methane belongs to the **alkane** homologous series. It is also an example of a **hydrocarbon**, which means it consists of the elements hydrogen and carbon only.

Alkanes are the simplest family of organic compounds. The first member of the alkane family is methane, CH_4, with one carbon atom which can form four bonds to hydrogen atoms.

Each homologous series or family has a general formula. For the alkanes it is C_nH_{2n+2}. This means you can work out the formula for any alkane if you know how many carbon atoms there are. The names of organic compounds tell you how many carbon atoms are present. A special prefix is used no matter what the homologous series:

- meth – one carbon (methane)
- eth – two carbons (ethane)
- prop – three carbons (propane)
- but – four carbons (butane)
- pent – five carbons (pentane).

Hint

A mnemonic to help you remember the prefixes for the first five organic compounds is Monkeys Eat Peanut Butter Pancakes.

The products of the **complete combustion** of all alkanes are carbon dioxide and water. Carbon dioxide is a greenhouse gas, making the combustion of alkanes a contributor to the problem of global warming (Chapter 11). All of the alkane family combust to form the same products.

methane + oxygen → carbon dioxide + water

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

However, in a limited amount of oxygen, **incomplete combustion** will occur instead. A product of incomplete combustion is carbon monoxide, which is produced instead of carbon dioxide.

methane + oxygen (limited) → carbon monoxide + water

$$2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$$

If there is not enough oxygen present, carbon atoms may additionally be released as small particles of black soot, which are often classified as particulates. In Chapter 11 we will explore the effects of these substances as **pollutants**.

ACTIVITY: Are you aware of the impacts of extracting fossil fuels?

ATL

- Communication skills: Read critically and for comprehension; Paraphrase accurately and concisely; Structure information in summaries, essays and reports
- Organization skills: Plan short- and long-term assignments; Meet deadlines; Use appropriate strategies for organizing complex information

The extraction of all fossil fuels has devastating effects on the environment, even when everything goes to plan. Your task is to write a report evaluating the impact of one of the methods of extraction of fossil fuels.

Search for information on the effects of different extraction processes. Use this to decide which one you want to focus on. **Explain** the problem or issue with the extraction of the fossil fuel you have chosen, ensuring you emphasize the local or global need for the extraction process. You should include a scientific discussion of the extraction process. **Evaluate** the method of extraction by weighing up its benefits and limitations, making reference to environmental, social, economic or political world factors.

Demonstrate appropriate communication skills for a scientific audience, using and **explaining** key scientific terminology and **documenting** all your sources in full.

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

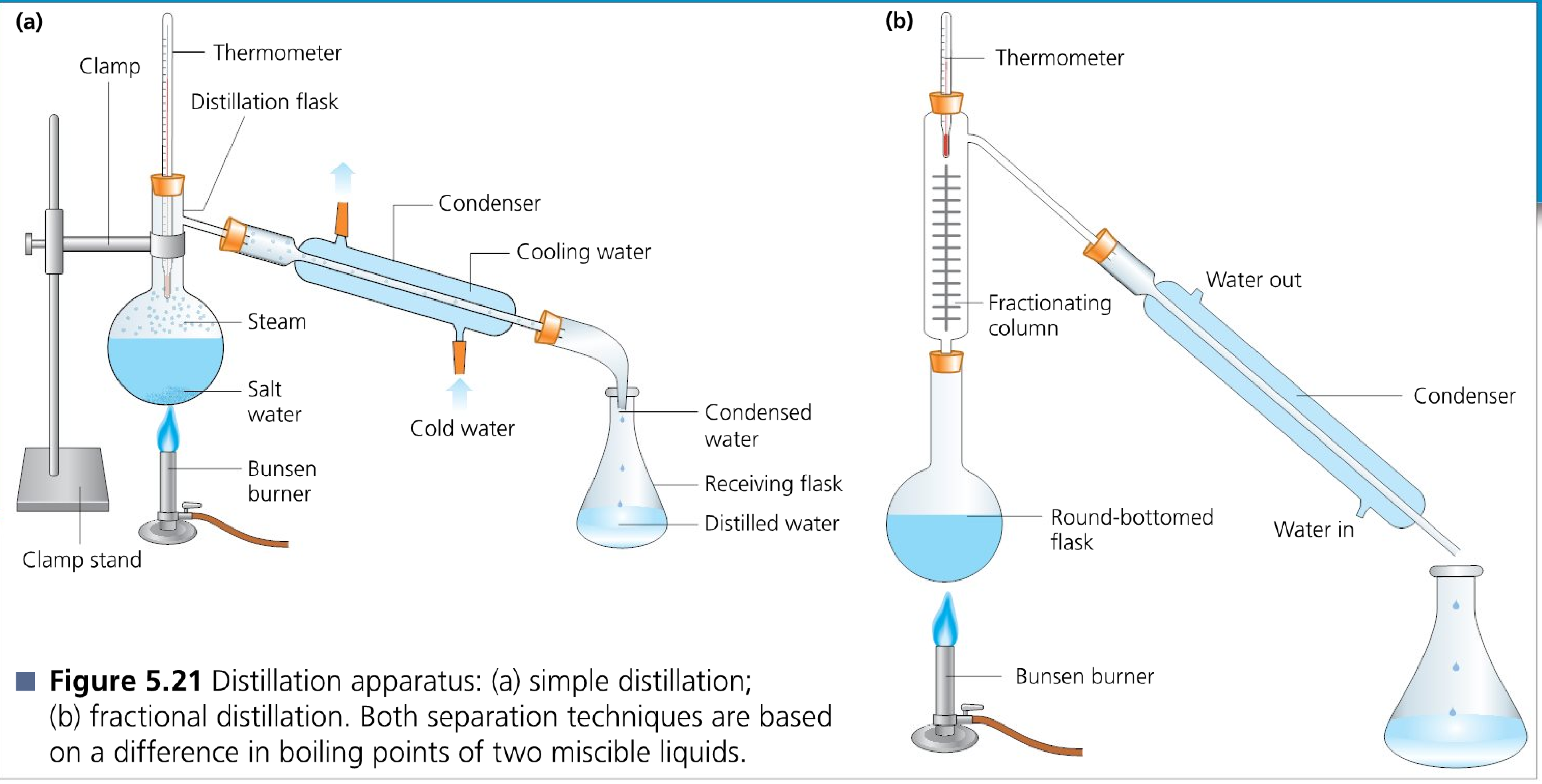
THE EXTRACTION OF FUELS

We depend on the extraction of fossil fuels to provide us with energy, but also to create raw materials for products such as plastics, paints, crayons, nail varnish, lipsticks and vaseline. Fossil fuels were formed millions of years ago, deep underground. Coal was formed from prehistoric plant material while crude oil was formed from dead marine organisms. In areas deep underground, where pressures and temperatures were extremely high, natural gas was formed instead of crude oil. As fossil fuels take millions of years to form and we are using them at a much faster rate than they are forming, they are a finite or **non-renewable** resource.

Coal is extracted from the ground through mining. Crude oil is extracted by drilling wells into the ground where it is located. Natural gas can be found deep underneath the surface of the Earth in rock formations, both on land and underneath the ocean floor. It is often found at locations where there are oil deposits, though more recently new technologies are being tested to try to extract natural gas from more challenging sources. You can find out more about this in *MYP Sciences by Concept 3*: Chapter 1, *You don't know what you've got until it's gone* and at the following link: **www.nationalgeographic.org/encyclopedia/natural-gas/**

When crude oil is extracted from the ground, it contains a mixture of hydrocarbons of varying chain lengths. **Fractional distillation** then separates the components of the mixture into **fractions**.

Figure 5.20 (a) A coal mine; (b) platforms for the extraction of oil and natural gas in the Adriatic Sea offshore Ravenna



■ **Figure 5.21** Distillation apparatus: (a) simple distillation; (b) fractional distillation. Both separation techniques are based on a difference in boiling points of two miscible liquids.

ACTIVITY: Reviewing separation techniques

ATL

- Communication skills: Take effective notes in class
- Organization skills: Use appropriate strategies for organizing complex information

In *MYP Sciences by Concept 1:* Chapter 2 you learnt about: filtration, decanting, evaporation, chromatography, separating funnel and simple distillation. How a mixture is separated depends on the properties of the substances it contains.

On small index cards or similar, record the key points about each of the separation techniques. Make sure you:

- **identify the property that allows substances to be separated using each method**
- **state an example of two substances that can be separated using this technique**
- **draw a labelled diagram of the technique**
- **outline the steps in the separation process.**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

Fractional distillation is an additional separation process to those you learnt about in *MYP Sciences by Concept 1:* Chapter 2. It works on the same basis as simple distillation, separating two miscible liquids but also includes a fractionating column (which is usually a column packed with glass beads). The fractionating column is what enables two miscible liquids with a small difference in boiling point (<30 °C) to be separated.

As the mixture is heated in the round-bottomed flask, the liquid particles gain enough kinetic energy to overcome the forces of attraction between them. The gas particles rise up into the column. The column, however, is at a much lower temperature than the gas particles, causing them to condense and fall back into the round-bottomed flask. This process repeats itself until the fractionating column starts to increase in temperature allowing the vapours to move further up the column. Gradually the column heats up to the temperature of the liquid with the lower boiling point. This enables these gas particles to move up the length of the column and into the condenser, while the gas particles of the liquid with the higher boiling point will continue to condense back into the round-bottomed flask.

While the lower boiling-point liquid is being collected, the temperature on the thermometer will remain constant (and should show the boiling point of the liquid with the lower boiling point). Only when all of this liquid has been collected, will the temperature on the thermometer start to increase.

Figure 5.22 shows a crude oil fractionating column and the different fractions that result from the process.

The boiling point of the hydrocarbon is affected by the strength of the intermolecular forces between the hydrocarbon molecules. The longer the chains (i.e. the greater the size of the molecule and the larger the mass), the stronger the intermolecular forces and the higher the boiling point. This means that the short-chain hydrocarbons are collected in the fractions towards the top of the column and the long-chain hydrocarbons in the fractions at the bottom. Natural gas (which is mainly methane but also contains other molecules with fewer than four carbon atoms) passes directly through the column and is removed through the top.

Table 5.1 shows the properties of the different fractions and some of their uses. The short-chain hydrocarbons make better fuels than the long-chain ones, which means there is greater demand for these fractions. Further, the separation process results in a larger amount of the less useful, long-chain fractions. The longer chains, therefore, often undergo a process called **cracking**, whereby they are broken down into more useful shorter chains. The shorter chains can also be converted to more stable branched chains or rings using a catalyst in the process of **reforming**.

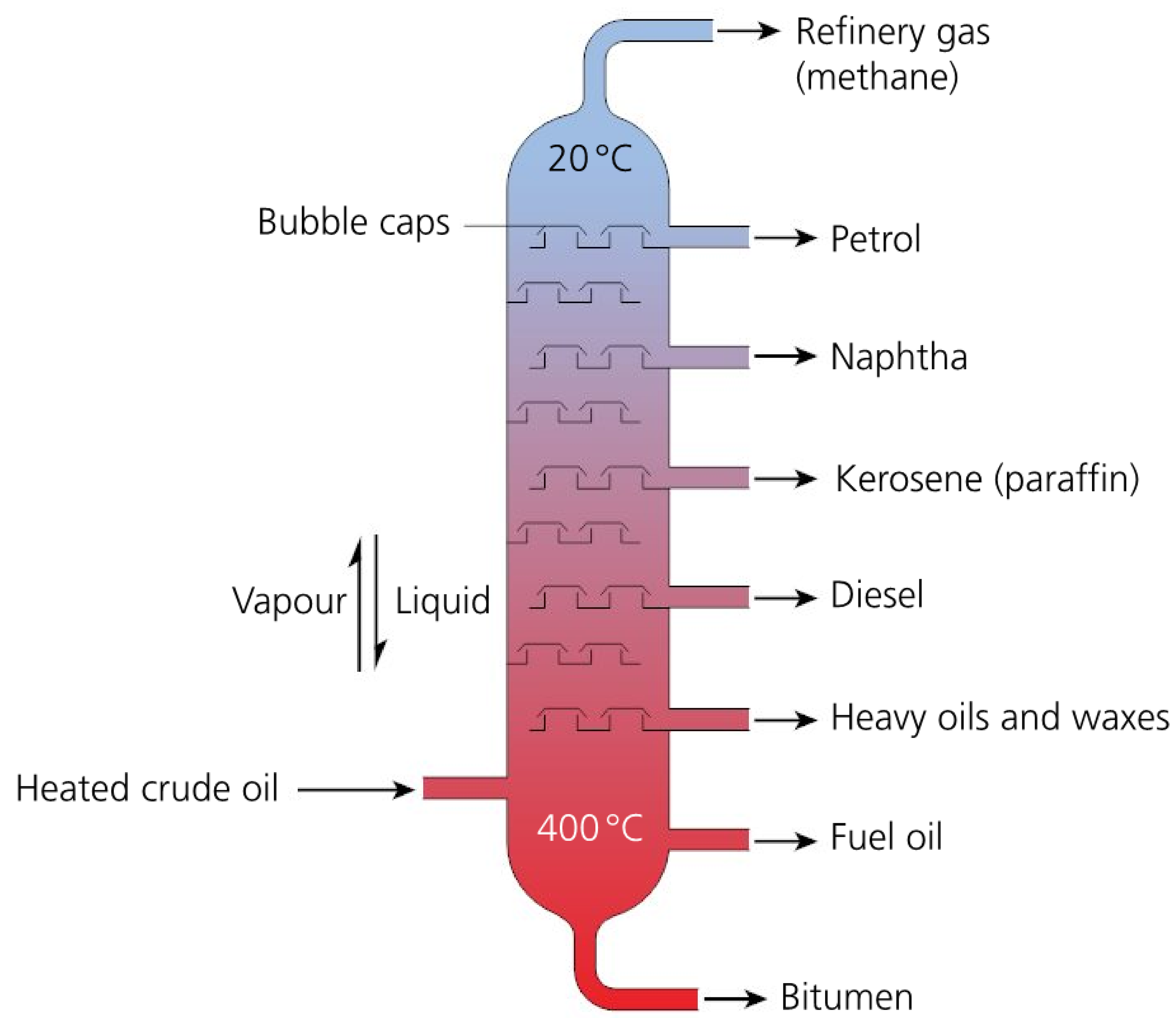


Figure 5.22 Crude oil fractionating column

Links to: Individuals and societies

The availability of electricity in our homes or petrol in our cars is linked to world political events. In Individuals and societies you will inquire into the causes of these tensions and better understand the impact of these events.

Name of fraction	Boiling point range/°C	Number of carbon atoms in hydrocarbons	Uses
natural gas	<40	1–4	camping gas, industrial gas known as LPG (liquified petroleum gas)
petrol/gasoline	40–210	5–8	fuel for cars
kerosene (paraffin)	190–270	11–16	jet fuel, heating and lighting oil
diesel oil/gas oil	270–360	14–20	oil for cars, lorries, buses
heavy oils and waxes	360–540	20–40	lubricating oils for machines and vehicles; paraffin wax for candles and waxes
fuel oil	>540	30–40	fuel for ships, fuel for central heating
bitumen	>540	>C50	roads, roof surfaces

Table 5.1 The properties of the different fractions and some of their uses

How do we use energy for motion?

CONNECTIONS AND EXPLANATIONS

Look at the images in Figure 5.23 and **discuss** these questions: What do you notice about the images? What might connect them? Why did these things come to be this way?

■ **Figure 5.23** (a) The *Titanic,* (b) a Boeing 777, (c) a Porsche 911

The images in Figure 5.23 show modes of transport. The *Titanic* was propelled by three massive steam engines. The Boeing 777 airliner has two jet engines. The Porsche 911 is a high-performance sports car propelled by one gasoline engine. While all very different, they are all solutions to the same engineering problem: how to generate kinetic energy from stored energy. To understand how they are connected, and how each is different, we might consider the amount of power they produce.

If you walk up a steep hill, you will feel tired at the top. The work done will be the energy changed, in this case the change in gravitational potential energy:

$$W = mg(h_2 - h_1)$$

What happens if you run up the hill? You will most likely feel more tired, since you are doing the work in a shorter time. Since the equation above does not include time, we need a different concept to understand the effect of doing work at a different rate. The physics concept of power is used to account for the difference in time:

$$\text{power, } P\text{ (W)} = \frac{\text{work done (J)}}{\text{time (}s\text{)}}$$

The power of a machine is measured in watts (W), named after the experimenter, engineer and industrialist James Watt (1736–1819).

1 watt = 1 joule of work done in 1 second

For our example, the force against which we are doing work is the weight caused by the force of gravity, $F = mg$. If we generalize for any force using our work done equation:

$$P = \frac{Fd}{t}$$

$$v = \frac{d}{t}$$

So

$$P = Fv$$

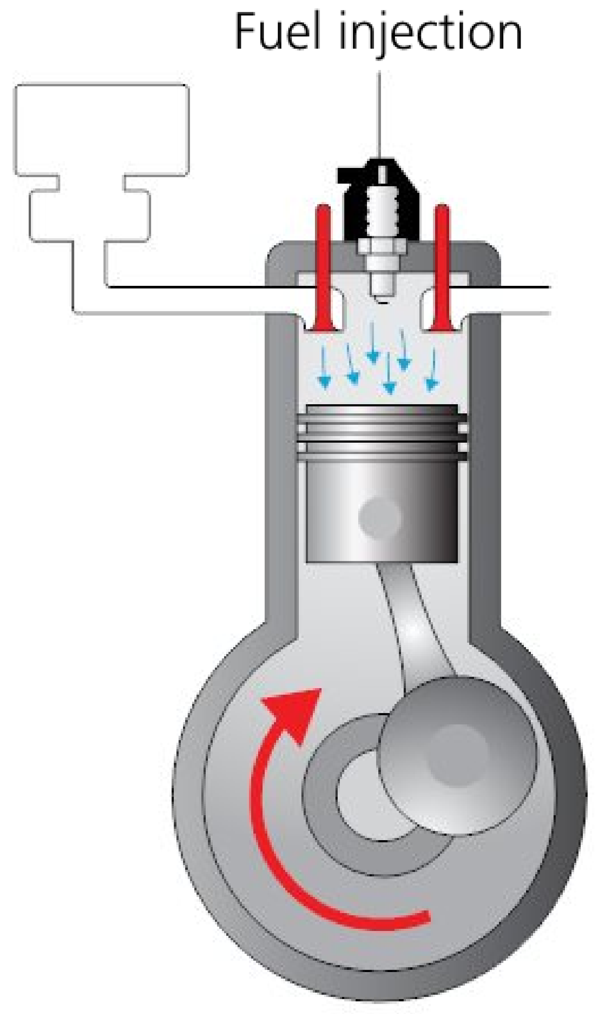
Power is a very useful concept which applies equally well to mechanical machines as to electrical and other kinds of machines (more details in Chapter 8).

Each of the machines in Figure 5.23 generates work from combustion of fossil fuels (coal, kerosene and gasoline, respectively), releasing the energy as heat (as well as light and sound). The heat causes the gases released from the combustion to expand rapidly and this mechanical energy

is then transferred to the vehicle. If we wish to compare the power produced by each of the engines, we should factor in the mass of the engine using the ratio of power produced to weight of engine, sometimes called the **specific power**.

Engine	Power/kW	Weight of engine/kg	Power (kW) / Weight (kg)
Titanic	16 000 (average)	1 000 000	0.016
Boeing 777*	83 000	7 000	12
Porsche 911*	309	150	2

■ **Table 5.2** Power-to-weight ratio of engines (* Note that the values given are approximate only and averaged for different possible engine variants)



■ **Figure 5.24** The cylinder of an internal combustion engine

In engineering, it is still common to use non-metric units for engine power. Common units are the **horse-power (hp)** or **brake horse-power (bhp)**. You can use this site to compare the units: **www.which.co.uk/reviews/cars/article/driver-calculators-and-tools/power-converter-bhp-ps-and-kw**

When we look at it this way, the *Titanic* doesn't look so impressive. On average, one engine of a Boeing 777 produces twice the thrust of all the *Titanic*'s steam engines together! Even the much smaller Porsche gasoline engine produces hundreds of times the specific power of the *Titanic*.

However we should be aware from our understanding of combustion chemistry that fossil-fuel engines bring other problems with them, such as the pollution they produce, the environmental impact of oil extraction and its limited availability. One possible solution to this is to use electric motors to power vehicles instead.

Electric motors have many advantages over diesel or gasoline engines, although they have some disadvantages too, as we will explore in the Take action! *The future of the automobile* on page 136.

Worked example

The cruising speed for a Boeing 777 is 900 km h⁻¹. **Calculate** the force the aircraft engines produce in maintaining this velocity.

Solution

From our power equations,

$$P = Fv$$

Rearranging for force,

$$F = \frac{P}{v}$$

We know that one of the Boeing's engines produces 83 MW of power, so the total power is 166 MW.

A cruising speed of 900 km h^{-1} = $\frac{900 \times 1000}{3600}$ m s^{-1}, so v = 250 m s^{-1}

Therefore the total thrust produced is

$$F = \frac{166 \times 10^6}{250}\,\text{N}$$

$$F = 664\,\text{kN in total or } 332\,\text{kN per engine}$$

Now check the result of the calculation by searching for **thrust of Boeing 777 engine**. Does this number seem about right?
Suggest what factors might account for any difference between our calculated value and the real value.

What are enzymes and what is their role in cellular metabolism?

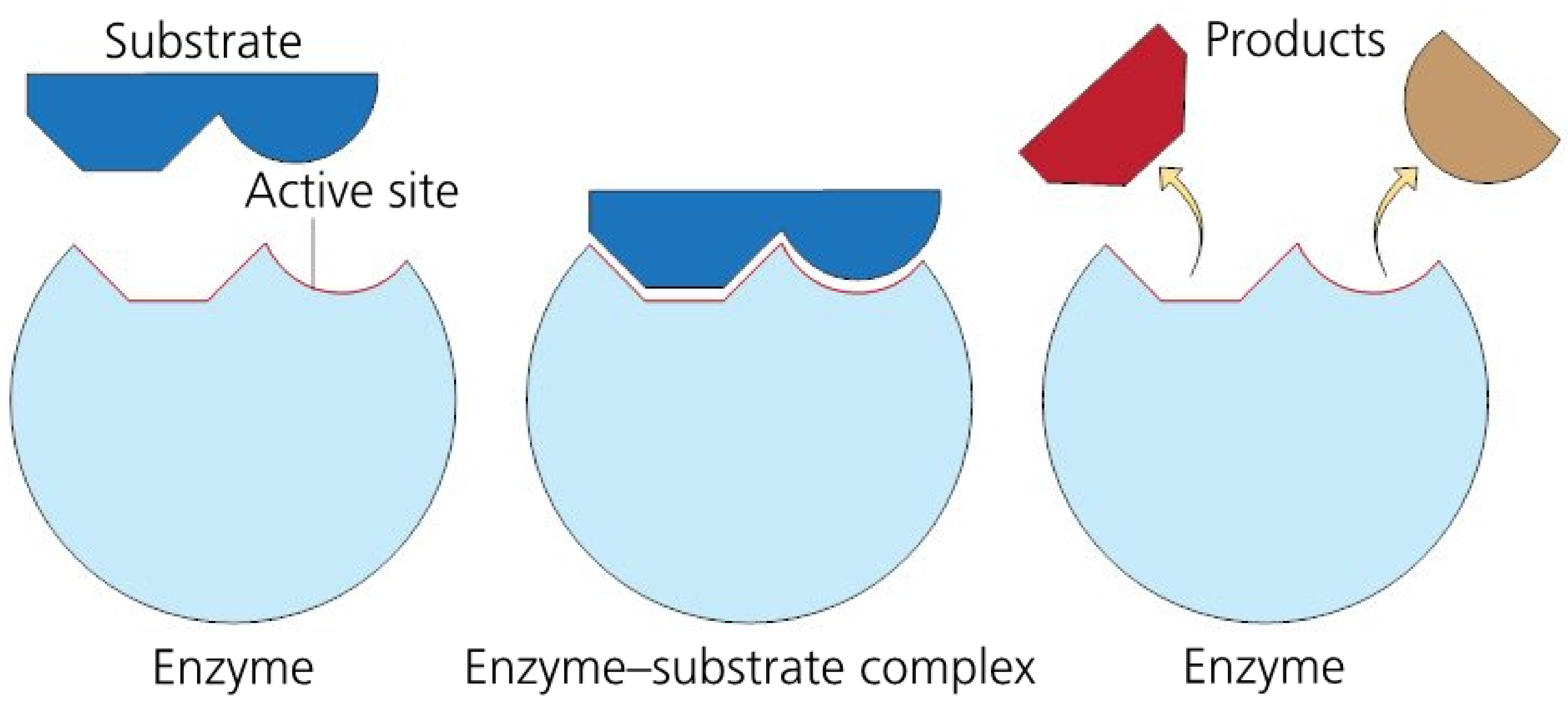


Figure 5.26 An enzyme-catalysed reaction

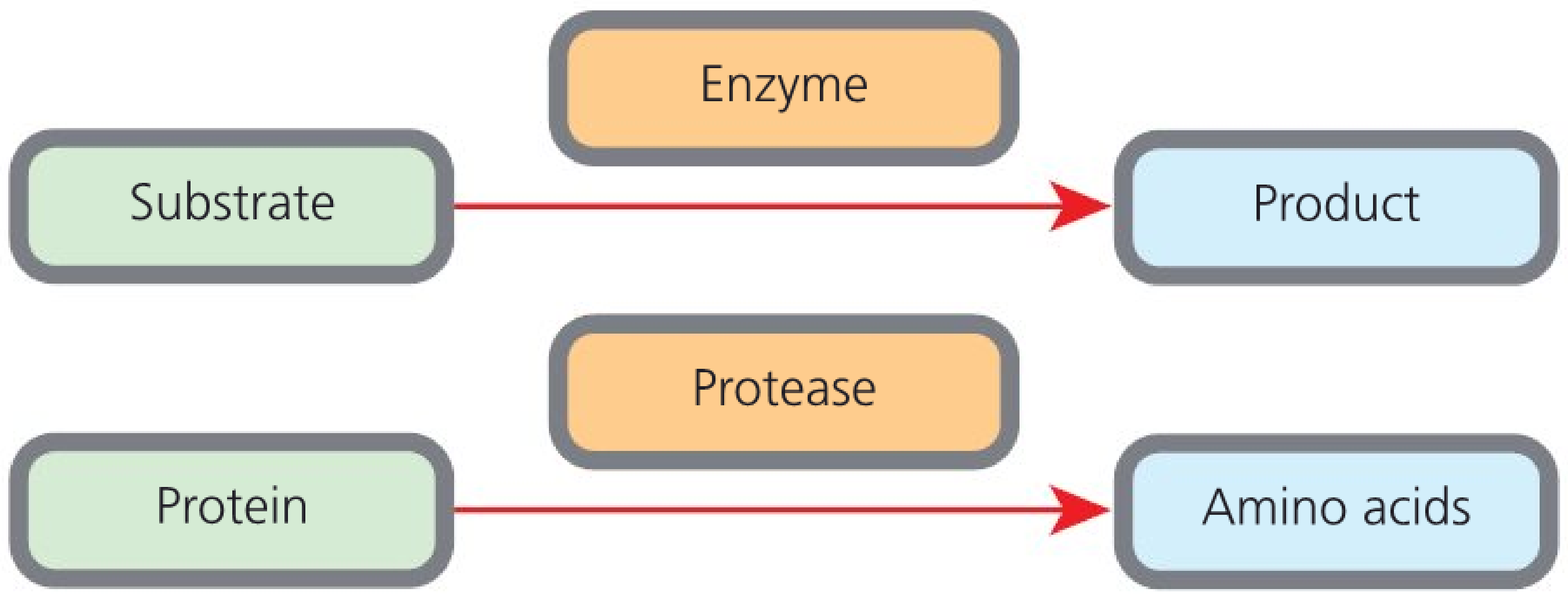


Figure 5.25 An example of a reaction that occurs in the digestive system with the help of enzymes

In order to survive, a cell must be able to respond quickly to changes in its environment. It should also meet its needs of energy, growth or repair. All these processes involve thousands of biochemical reactions referred to as **cellular metabolism**. According to its needs, the cell controls which reactions happen at what speed with the help of special biological **catalysts** called enzymes (see Chapter 10 for more on catalysts). Enzymes control the metabolic pathways responsible for building up or breaking down important substances inside and outside cells.

HOW DO ENZYMES WORK?

Enzymes are proteins that act on reactants called **substrates** and convert them into products (see Figures 5.25 and 5.26). This process may involve breaking substrates down into simpler substances (**catabolism**) or joining two or more substrates together to make new products (**anabolism**). Enzymes themselves remain unchanged but without enzymes, chemical reactions would take much longer to happen or may not happen at all!

You will notice that enzyme names end in the suffix '-ase' preceded by the substrate on which the enzyme acts, for example protease, carbohydrase, etc.

EXTENSION

Enzymes are sensitive molecules and some only operate under certain conditions. There are several factors that affect their function, one of which is temperature. Most enzymes in plants and animals are almost inactive at very low temperatures. Equally, when subjected to high temperatures, their shape and structure is destroyed, they can no longer function and they are said to be **denatured**. Search **factors, enzyme, activity** to find out more about other factors that affect enzyme activity.

EXTENSION

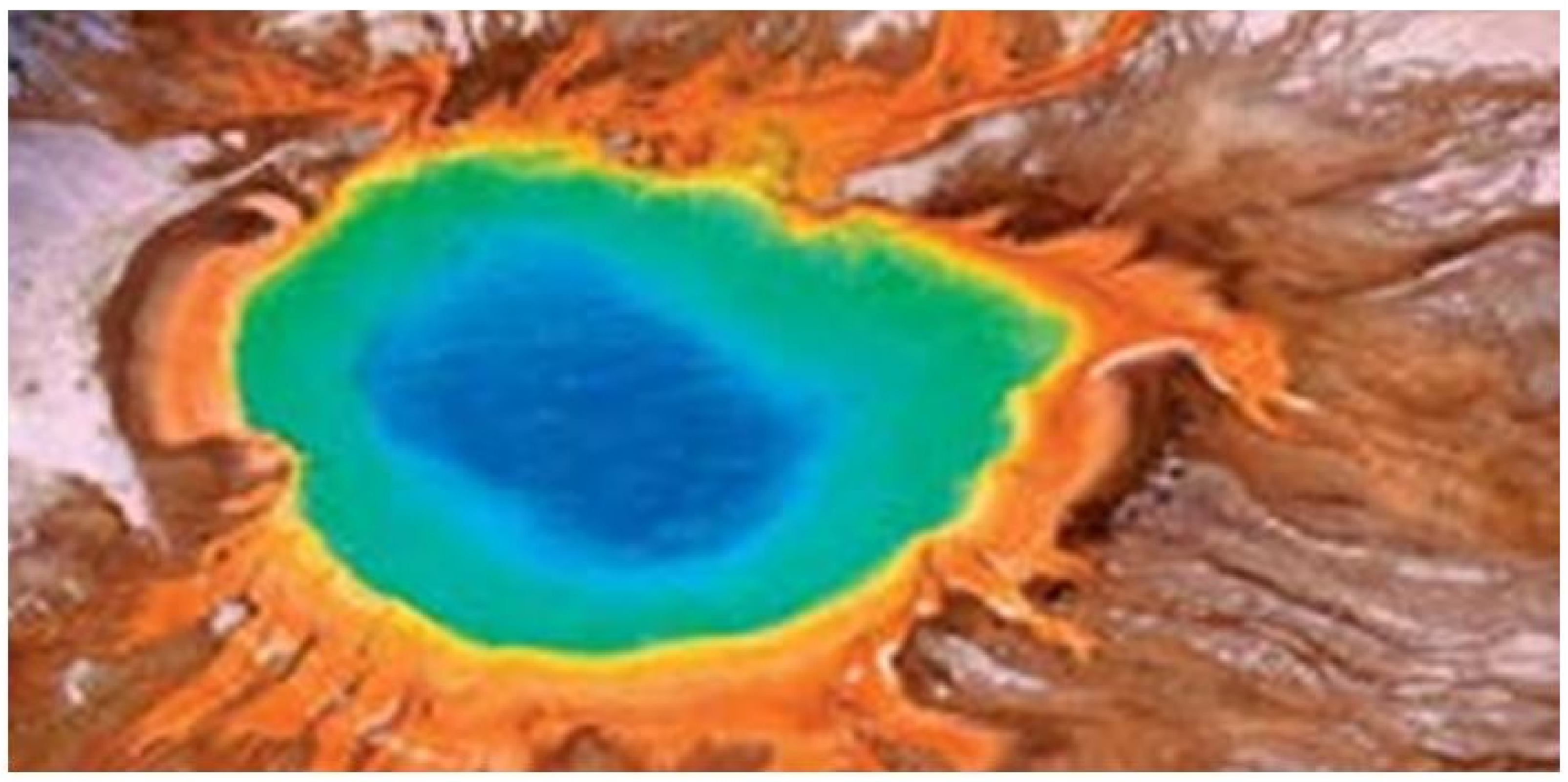
Search: **active site**, **lock and key mechanism**, **enzyme-substrate complex** to find out the main mechanism by which enzymes work. Are there any other mechanisms? Enzymes often depend on other chemicals called **cofactors** to work properly. These could be inorganic (often minerals) or organic (**coenzymes**). Enzymes may also be inhibited by enzyme **inhibitors** such as various poisons. Watch this video to learn more: https://youtu.be/ok9esggzN18

Where do these cofactors bind on an enzyme?

THINK–PUZZLE–EXPLORE

Figure 5.27 shows a hot spring with natural colours caused by special thermophilic microorganisms that live in it.

Think about how these organisms are able to survive at such high temperatures. What more **puzzles** do you have? What does it make you want to **explore**?



■ **Figure 5.27** Hot spring at Yellowstone National Park, USA

ACTIVITY: Hire the best candidates!

ATL

- Communication skills: Negotiate ideas and knowledge with peers and teachers; Organize and depict information logically
- Collaboration skills: Delegate and share responsibility for decision-making; Exercise leadership and take on a variety of roles within groups
- Creative-thinking skills: Apply existing knowledge to generate new ideas, products or processes
- Information literacy skills: Present information in a variety of formats and platforms
- Critical-thinking skills: Gather and organize relevant information

In this activity, you will consider the cell as a company looking to recruit employees (enzymes) to perform key functions within its structure. You will build online profiles in the form of infographics for specific enzymes as part of the recruitment process.

You may wish to review examples of infographics here: www.compoundchem.com/infographics/

In groups, carry out the following tasks.

1 **Pick one of the following types of cells for your recruitment drive.**

muscle cell, white blood cell, exocrine cell, bacterial cell, palisade cell, amoeba cell, fungal cell, yeast cell

2 **Create a name for your company which links to the cell of your choice and appoint a manager who will research about their 'cell company's' role, function and needs.**

3 **The rest of the team will work separately as human resources advisors. They must find out the names of at least two key enzymes (candidates) that their 'cell company' needs to survive and perform its functions.**

4 **Write the name of each candidate (enzyme) on a sticky note.**

5 **Assign each member of your group an enzyme and gather key relevant information that will be used to build a candidate profile. Include properties such as the optimum pH or temperature, preferred substrate and key roles in the cell.**

6 **The enzyme profile will be in the form of an infographic which will act as a CV. You may use this free tool:** www.creativebloq.com/infographic/tools-2131971 **or search for free, infographics, tools. Apply scientific language and use relevant diagrams/images to illustrate your infographic. Keep a record and document all of the sources used in a separate file that you will hand in to the company manager later. You may wish to collect the files in an online dropbox or cloud storage.**

7 **Outline the reasons why this candidate should be recruited, highlighting key skills and properties and pointing at strengths and possible limitations/ weaknesses.**

8 **Once the winning candidates have been selected, managers should re-group with the rest of their team to get feedback. Introduce each of the new 'enzyme employees' with a short oral presentation. As a class, discuss and evaluate the selection made by the 'human resources' team.**

◆ Assessment opportunities

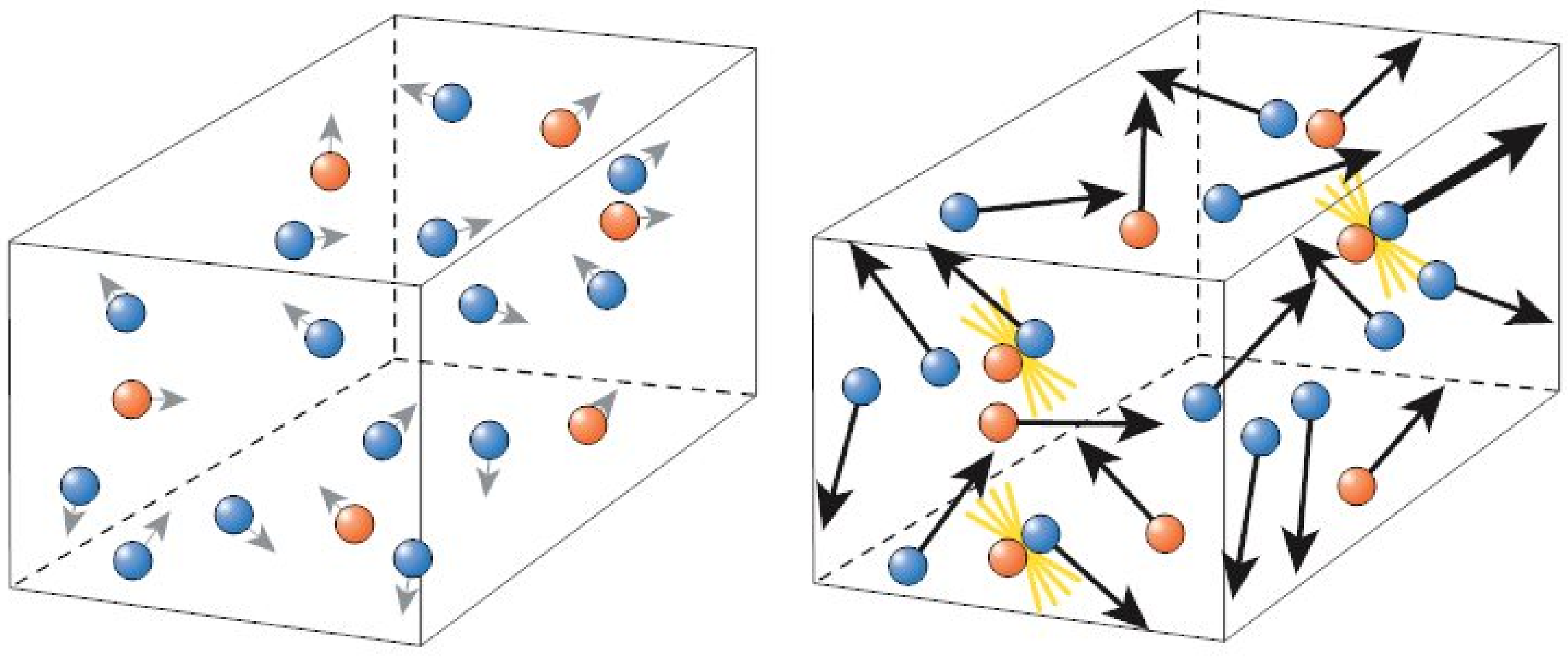
- ◆ In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding and Criterion D: Reflecting on the impacts of science.

How do enzymes improve our lives?

ENZYMES, NATURE'S ENERGY SAVERS!

Science has enabled us to extract enzymes in a purified form from microorganisms and make use of their natural catalytic properties to solve issues and save energy in many industrial and pharmaceutical processes. They are, for instance, used in biological detergents, in the production of lactose-free milk and in the treatment of wood waste. Before we explore this area further, let us first see how an enzyme's role in saving energy begins in the cell.

In Chapter 10 you will see how reactants must obtain the required **activation energy** before a reaction can proceed. Enzymes lower the required activation energy and allow the reactant (in this case the substrate) to be converted into the product more quickly. Raising the temperature also increases the rate of enzymatic reactions because the kinetic energy of the molecules is increased, maximizing the chances of the enzyme colliding with the substrate (Figure 5.28).



■ **Figure 5.28** Effect of temperature on increasing the kinetic energy of molecules inside cells

ACTIVITY: It'll all come out in the wash: saving energy with biological laundry detergent

ATL

- Creative-thinking skills: Make guesses, ask 'what if' questions and generate testable hypotheses
- Critical-thinking skills: Interpret data; Revise understanding based on new information and evidence

Stains often contain organic molecules, for example from foods, that can be broken down with the help of enzymes (see the section in Chapter 6 on digestive enzymes). Biological (bio) detergents contain enzymes while non-biological (non-bio) detergents do not contain enzymes and rely on chemicals to clean stains.

Task

You work in the research and development department of a company that manufactures household detergents. The company is testing a new biological laundry liquid before commercializing it with the aim of finding the lowest possible temperature at which the detergent is efficient. You are asked to perform a series of experiments to assess the performance of enzymes in the detergent and evaluate the product's efficiency at different washing temperatures. You will write your findings in a report that you will **present** to the rest of the team and senior managers.

You will test different types of enzymes on different stains at different temperatures. Your experiment must include a **control test** to compare the effectiveness of biological and non-biological detergents at certain temperatures. You may work in teams and each team could consider one factor to investigate.

- **Select your independent variable. Which factor will you investigate?**
- **What is the range of data that you will test? Consider, for example, how long you need to allow the detergents to wash the stains.**

- **Which dependent variable will you measure? How will you measure it?**
- **How will you collect data? How will you turn observations (qualitative results) about the cleanliness of fabric into quantitative data?**
- **What are the controlled variables in your experiment?**
- **Explain how you will manipulate your variables and how you will collect sufficient and relevant data.**

Inquiry question

Now that you have selected your variables, write an inquiry question that links the independent and the dependent variable and **explain** the question to be tested by a scientific investigation.

Hypothesis

Formulate a testable hypothesis to answer your inquiry question and **explain** it using correct scientific reasoning.

Materials

You will need to **select** the appropriate materials and equipment for your experiment but the following can be used as a guide:

- **non-biological powder or liquid laundry detergent (diluted, see *Method*)**
- **different enzyme solutions (protease, amylase and lipase; see Table 6.6 on page 154 of Chapter 6 for a list of digestive enzymes)**
- **stained fabric (you may make these yourself by staining pieces of fabric with milkshake, eggs, vegetable oil, chocolate sauce, etc.)**
- **beakers**
- **thermometers or heat sensors**
- **stirring rods.**

Method

Design a logical and complete method that will allow you to test your hypothesis.

Safety: Concentrated enzyme solutions are considered hazardous; wear eye protection and gloves and handle with care. If you get splashed with the enzyme solutions or the detergent, rinse off immediately with cold water. Wash your hands thoroughly and avoid touching your eyes after handling washed fabric.

Hint

Consider these guidelines when carrying out your investigation.

- Depending on the nature of your chosen stains, you could either add one type of enzyme or make a mix of enzymes.
- When diluting enzymes to make up solutions, read the data sheet that comes with the enzyme at purchase to help inform your dilutions. As a guide, you could dilute the detergent to 4–5 per cent to mimic the conditions in a washing machine.
- You will make up a biological detergent by adding a known amount of enzyme solution to fixed volumes of the non-bio detergent.

Results and interpretation

Once you have correctly collected, **organized**, transformed and **presented** your observations and your data into a table, **plot** a suitable graph of the mean of your results. Your graph must include units and axes labels.

Interpretation and conclusion

It is best if all the groups in the class share their results and conclusions. **Interpret** your data so as to **determine** the effect of your chosen independent variable on the effectiveness of the detergents.

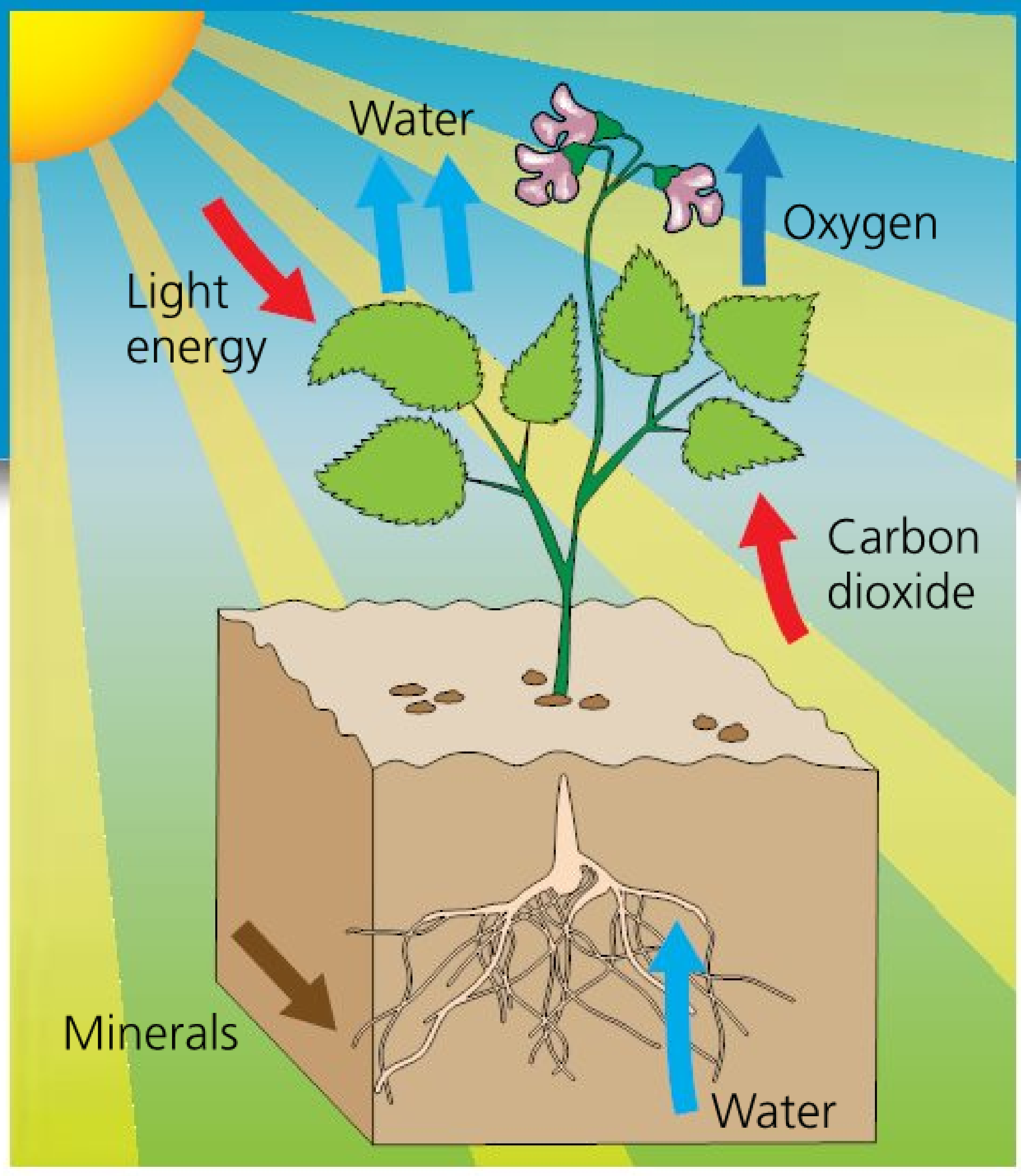
Evaluation

- **Evaluate your hypothesis based on the outcome of the investigation.**
- **Evaluate the validity of your method based on the outcome of the investigation.**
- **Explain improvements to the method that would benefit this investigation.**
- **Explain how this experiment could be extended.**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion B: Inquiring and designing and Criterion C: Processing and evaluating.

How does energy get transferred and transformed in living things?



■ **Figure 5.29** What a plant needs

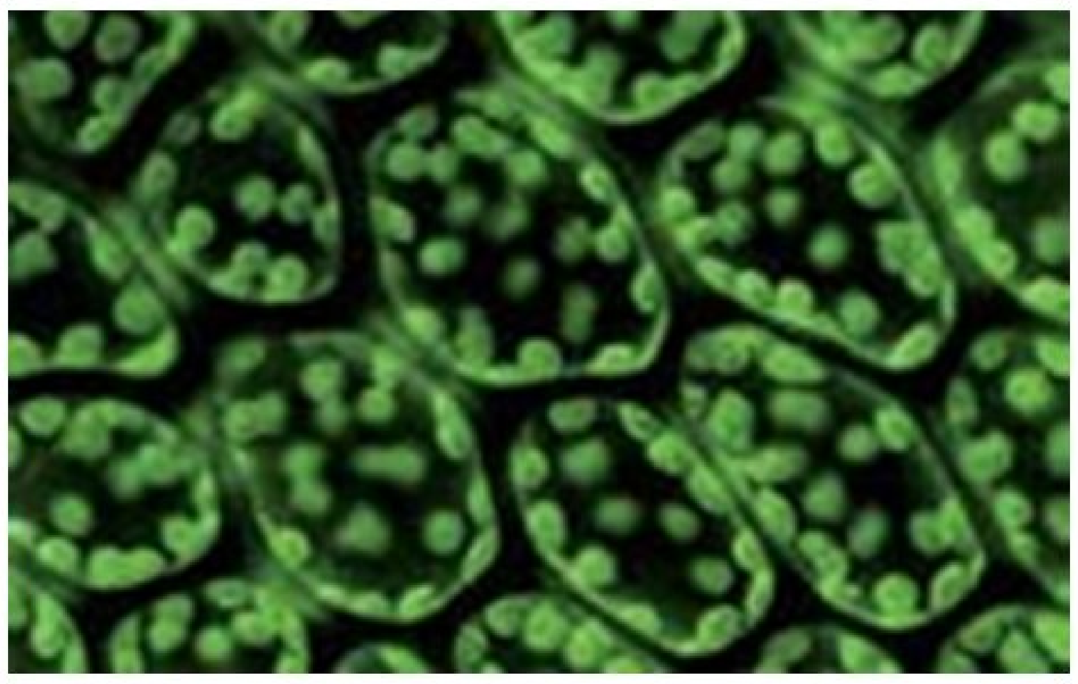
Energy is available in nature in many forms and organisms obtain this energy in different ways. Plants (and other photosynthetic organisms) are the only living things that are able to synthesize their own food by capturing the Sun's energy in the process of photosynthesis. They do so by transforming light energy into chemical energy and storing it in organic molecules within their cells and other structures in the plant.

HOW ARE PLANTS ADAPTED TO USE THE SUN'S ENERGY?

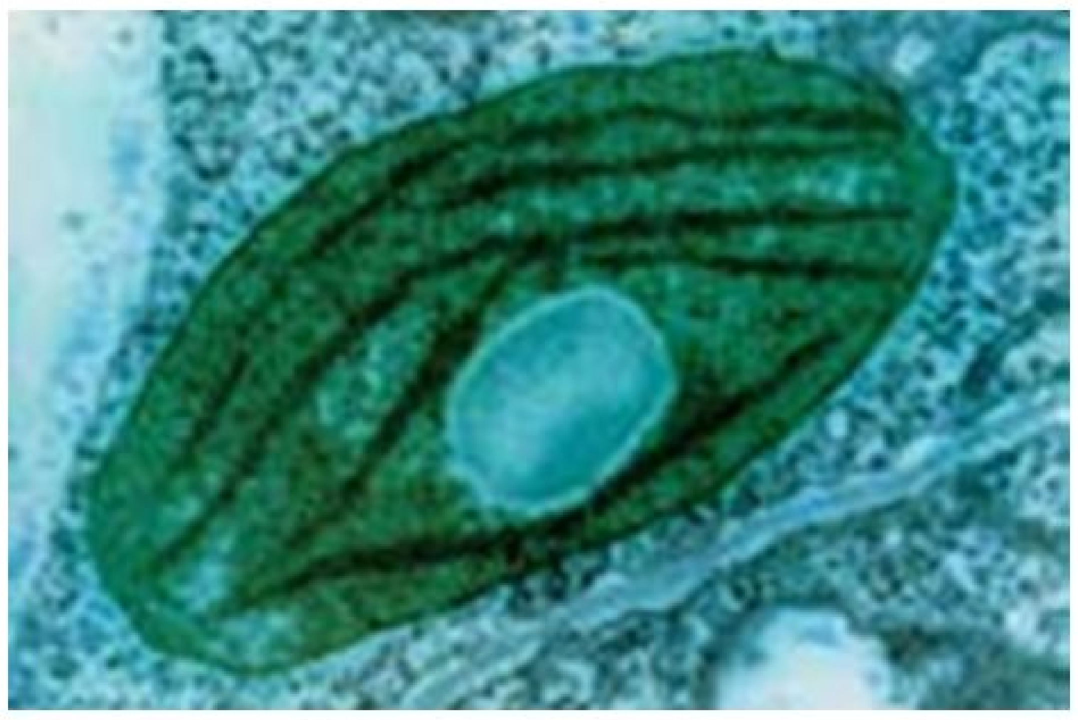
Plants, and other organisms that perform photosynthesis, have the ability to fix atmospheric carbon dioxide (CO_2) and, with the help of light, transform it into glucose (Figure 5.32). About 15 per cent of the total carbon dioxide in the atmosphere moves into photosynthetic organisms each year. Plant leaves are adapted to absorb light and allow the exchange of gases between the plant and its environment. **Palisade cells** contain a large number of green structures called chloroplasts (Figures 5.30 and 5.31). What colour can you see every time you look at a plant? What colour do these zoomed in structures show? **Chlorophylls** are special pigments located on the chloroplast membranes of plants which are able to absorb light at specific wavelengths (see Chapter 11). The shorter the wavelength, the more energy is carried by **photons** coming from the Sun and this energy transfers to electrons in pigment molecules. Chlorophyll a, chlorophyll b and **carotenoids** absorb light at slightly different wavelengths and together cover a wide range of the spectrum.

THINK–PAIR–SHARE

Look closely at Figure 5.29. Apart from sunlight, think of other requirements the plant has to make its own food. What is the chemical nature of these requirements (organic/inorganic)? Share your thoughts with your partner.



■ **Figure 5.30** Light micrograph of a section of a moss plant leaf



■ **Figure 5.31** Coloured transmission electron micrograph (TEM) of a chloroplast seen in the leaf of a pea plant

CONTROLLING PHOTOSYNTHESIS

So far we have looked at some factors on which photosynthesis depends. A change in the level of one of these factors can change the rate of photosynthesis at a particular time, even if the other factors are abundant. When one of these factors is in short supply, it becomes a **limiting factor**. For example, near to sunset light becomes a limiting factor for photosynthesis because it approaches its minimum value. Can you think of examples when other factors become limiting?

Word equation

Carbon dioxide + Water $\xrightarrow[\text{Chlorophyll}]{\text{Sunlight}}$ Glucose + Oxygen

Chemical equation

$$6CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6O_2$$

■ **Figure 5.32** The word and symbol equations for photosynthesis in plants

WHAT HAPPENS INSIDE THE CHLOROPLAST?

Photosynthesis is a **redox** process (see Chapter 8) of two phases: a light-dependent and light-independent phase. Through both phases, a series of redox reactions leads to the fixation of carbon dioxide and the production of sugar.

1 The light-dependent phase

This phase happens in the thylakoid (the flat green discs seen in Figure 5.31) where chlorophyll pigments are arranged in two **photosystems** called PSI and PSII.

The products of the light-dependent phase are:

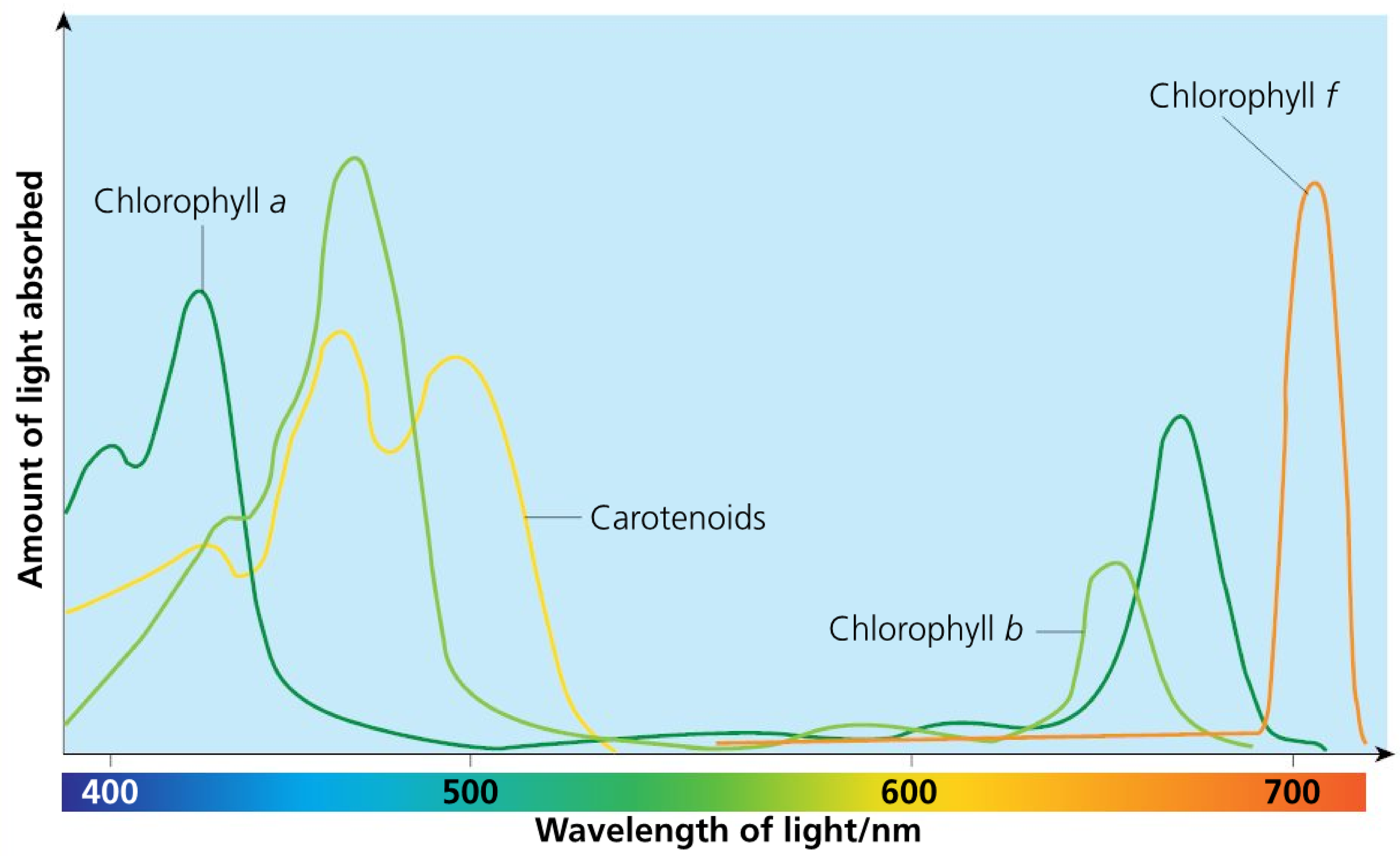
- **ATP** which is the main energy currency in the cell (see Figure 5.34); because of its high-energy bonds it can be used whenever chemical energy is needed. In this case it will enable the fixation of carbon in the next phase of photosynthesis.
- **NADPH** which will provide the hydrogen for the reduction of carbon dioxide to form carbohydrate.

ACTIVITY: Why are plants green?

ATL

- Critical-thinking skills: Interpret data; Draw reasonable conclusions and generalizations

The graph in Figure 5.33 shows how photosynthetic pigments in plant cells absorb visible light at different wavelengths. **Analyse** the graph then attempt the following tasks.

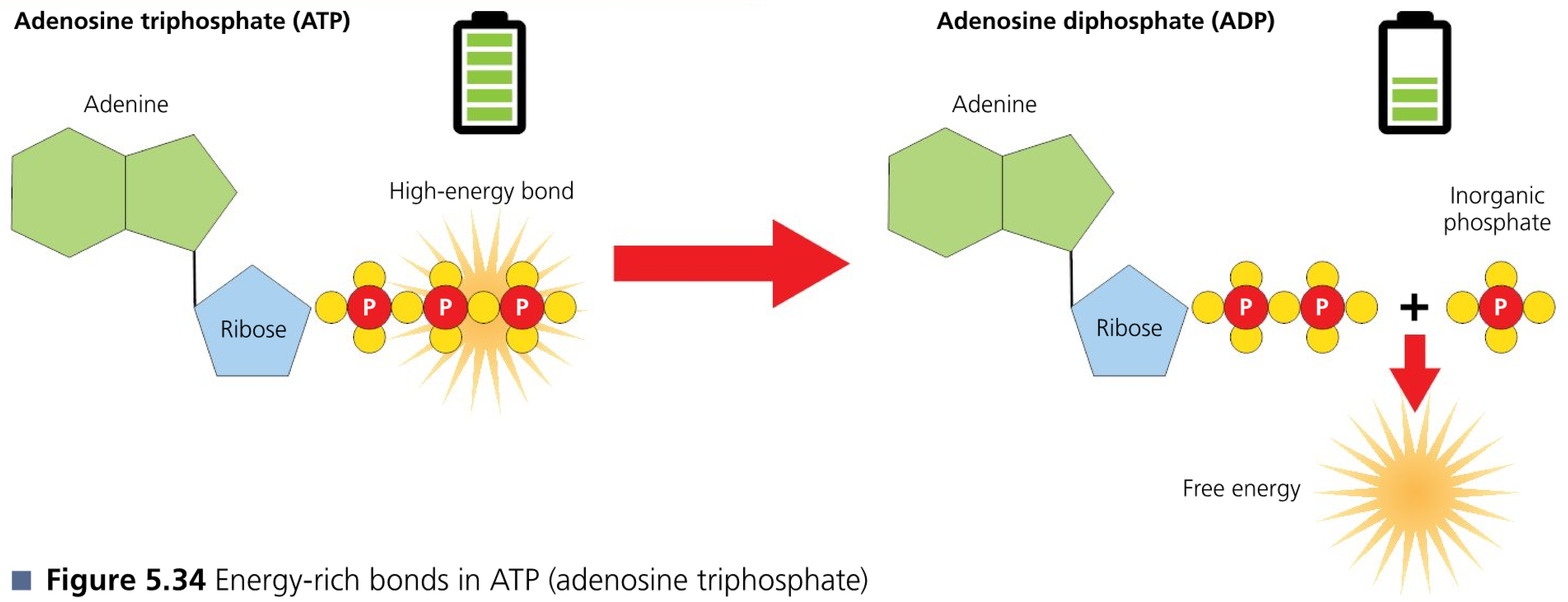


■ **Figure 5.33** Absorption spectra of photosynthetic pigments in plants

1. **State which wavelength(s) chlorophyll a absorbs the most, then chlorophyll b, then carotenoids.**
2. **State which wavelength is the least absorbed by all the pigments.**
3. **Apply your interpretation and understanding of these graphs to explain why plants are green. (You may wish to review *MYP Sciences by Concept 2:* Chapter 4 if unsure.)**
4. **Apply your understanding to explain why some algae are different colours such as orange and brown.**
5. **Chlorophyll f in the graph is not common in plants and is found in cyanobacteria. State which wavelength this pigment absorbs.**
6. **What would be the advantage for plants of having this type of chlorophyll? Justify with scientific reasoning.**

◆ Assessment opportunities

- ◆ In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.



■ **Figure 5.34** Energy-rich bonds in ATP (adenosine triphosphate)

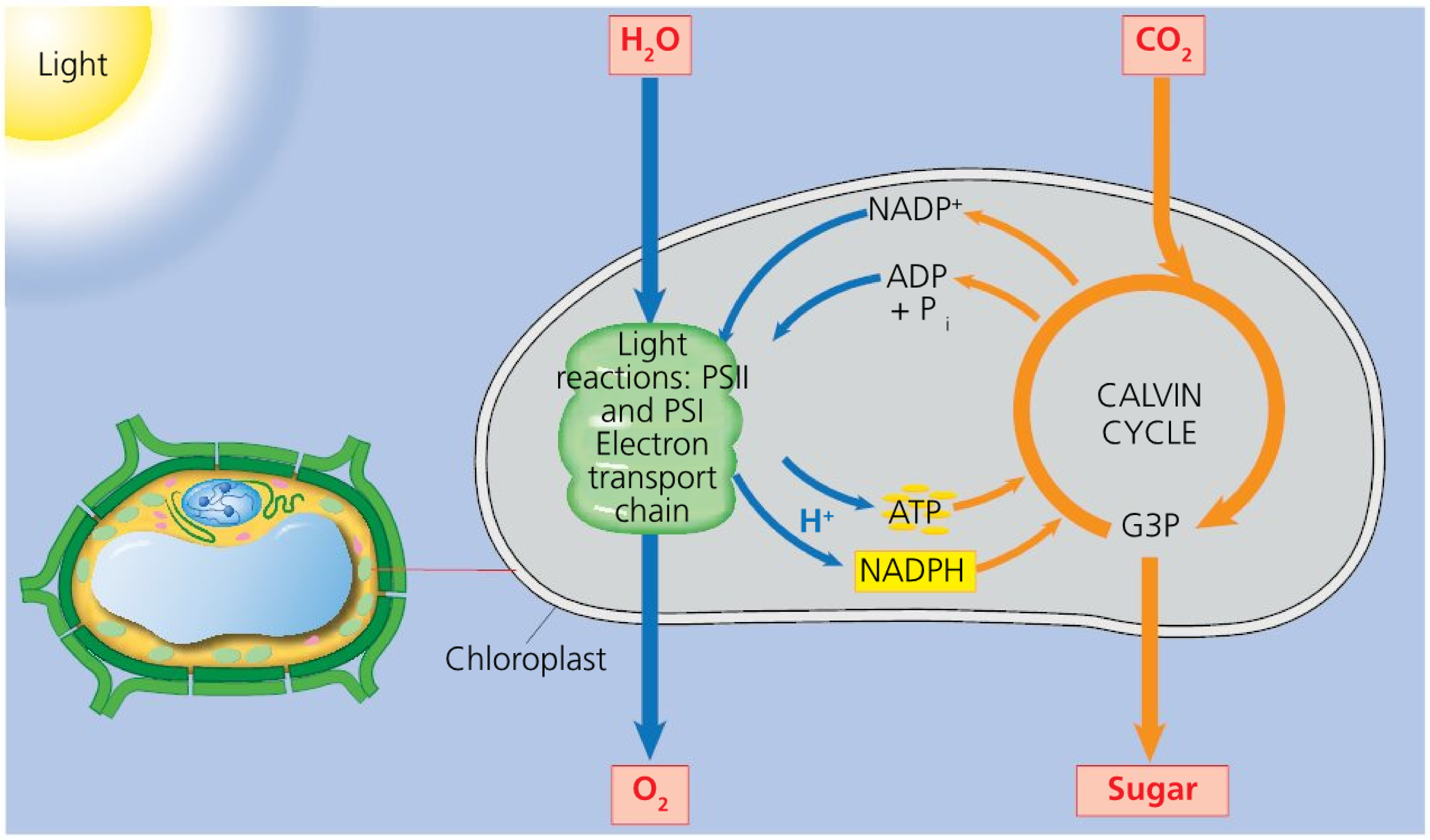
2 The light-independent phase

This phase does not require the Sun's energy directly but it uses the products of the light-dependent phase to fix CO_2 and produce sugar. The series of chemical reactions that happen during this phase is called the **Calvin cycle**.

The products of the light-independent phase are:

- glucose which is used to make other organic molecules needed in the plant
- oxygen which is released into the atmosphere.

The whole process is summarized in Figure 5.35.



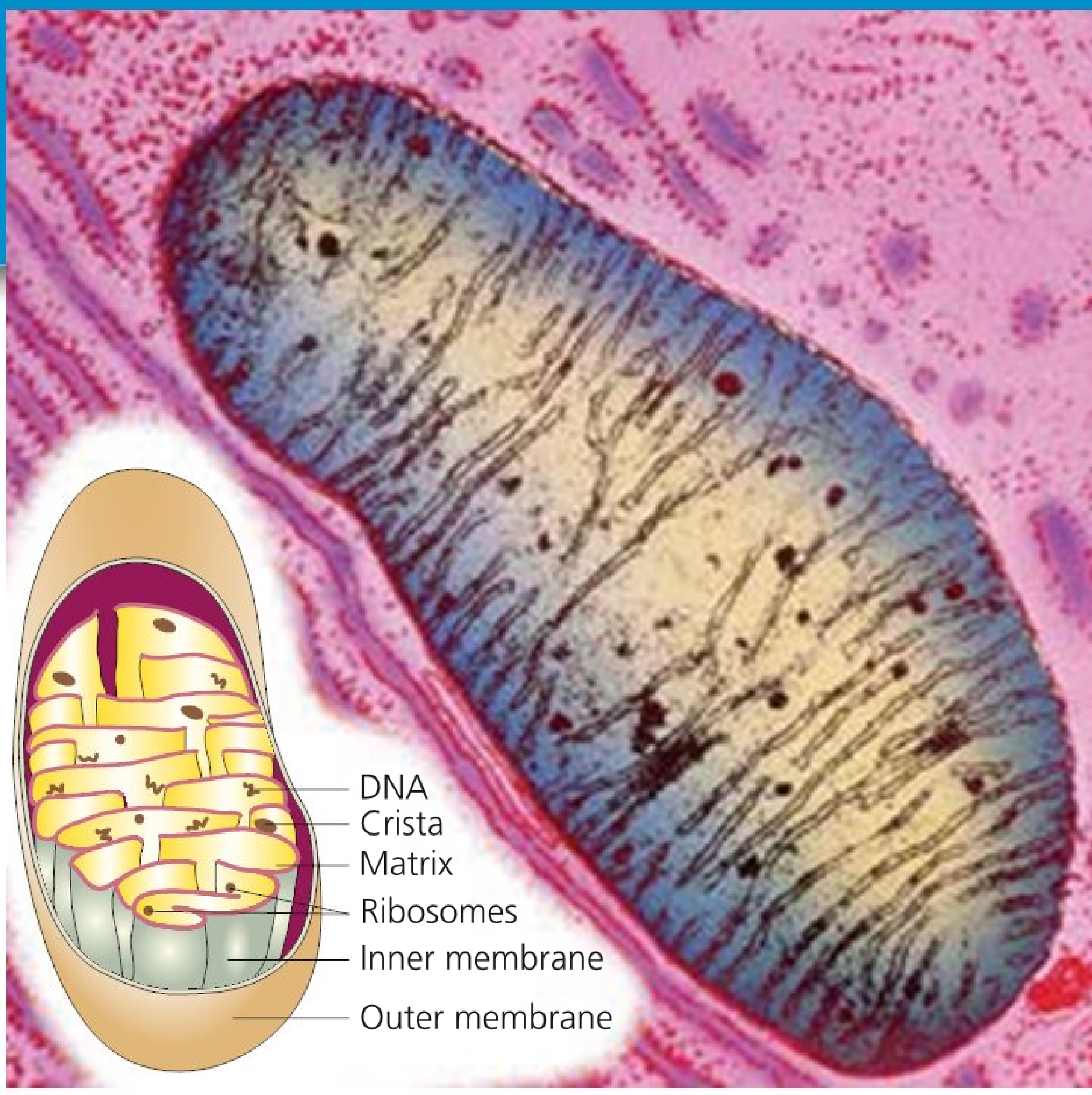
■ **Figure 5.35** Summary of light-dependent and light-independent phases in the chloroplast of a green plant

I USED TO THINK … NOW I THINK …

Imagine being able to see photosynthesis from space!

Watch this video from the NASA website: **https://climate.nasa.gov/news/956/seeing-photosynthesis-from-space-nasa-scientists-use-satellites-to-measure-plant-health/**

Has watching this video changed your perception about what we can and can't see?



■ **Figure 5.36** A mitochondrion (photo taken using an electron microscope) and an interpretative diagram

HOW IS THE ENERGY STORED IN THE PROCESS OF PHOTOSYNTHESIS TRANSFORMED IN CELLS?

Photosynthesis uses the Sun's energy for the building of organic molecules. Living things then obtain these molecules by feeding on plants or on other organisms that feed on them. Chemical energy stored in the molecules is then released by the process of **respiration**. Respiration is chemically similar to burning except that the energy in food is released gradually through a series of reactions controlled by enzymes and stored in the form of ATP to be used when and where needed.

There are two forms of cellular respiration: **aerobic** (requiring oxygen) and **anaerobic** (not requiring oxygen). Find out more by carrying out a video search: **video**, **cellular respiration**, **biology**, **introduction**.

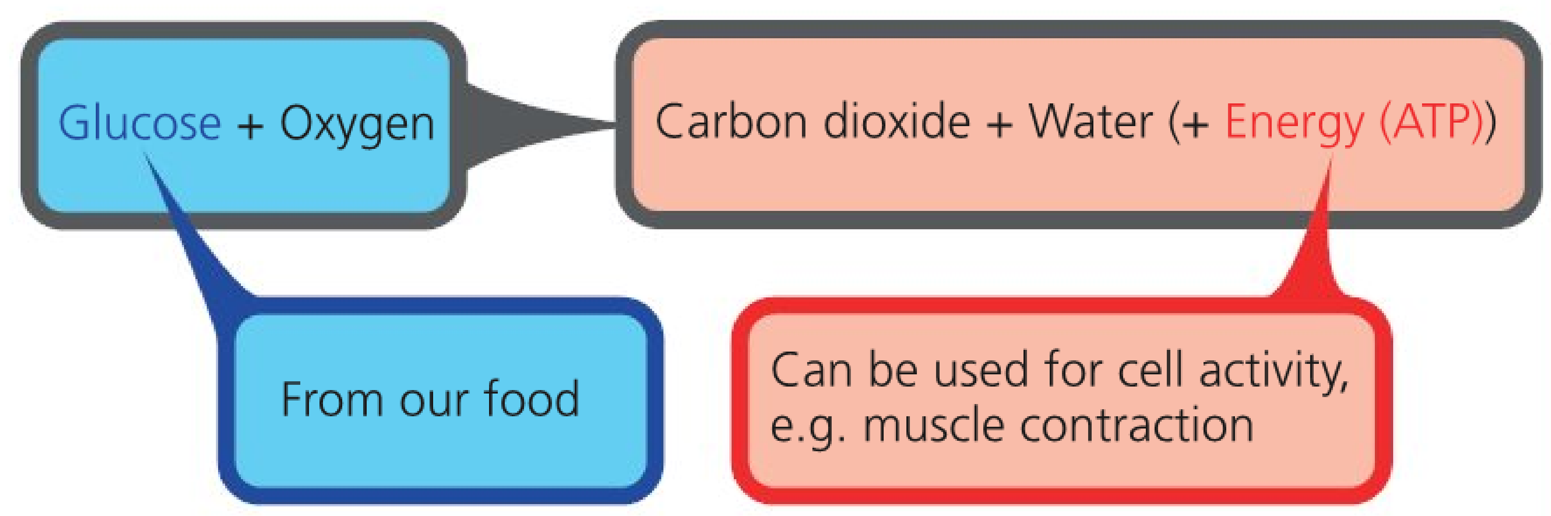
WHERE DOES RESPIRATION HAPPEN IN THE CELL?

Respiration happens in small organelles called mitochondria, present in all eukaryotic cells. Figure 5.36 shows this structure. The folds seen in the picture increase the surface area on which the reactions can take place. The matrix contains the respiratory enzymes.

WHAT HAPPENS DURING AEROBIC RESPIRATION?

WHAT MAKES YOU SAY THAT?

Look at the respiration equation in Figure 5.37 and recall the equation for photosynthesis covered earlier (Figure 5.32).



$$C_6H_{12}O_6 + 6\ O_2 \longrightarrow 6\ CO_2 + 6\ H_2O \text{ (+ Energy)}$$

■ **Figure 5.37** The equation for aerobic respiration

How are the processes of photosynthesis and respiration related? What makes you say that?

Glucose is oxidized in our cells in the presence of O_2 and CO_2 is produced. The gradual oxidation of food releases energy that is used to make ATP molecules as a temporary store of energy in the cell. Each molecule of glucose can produce up to 38 molecules of ATP! Because this reaction requires oxygen, it is called aerobic respiration and is an exothermic reaction.

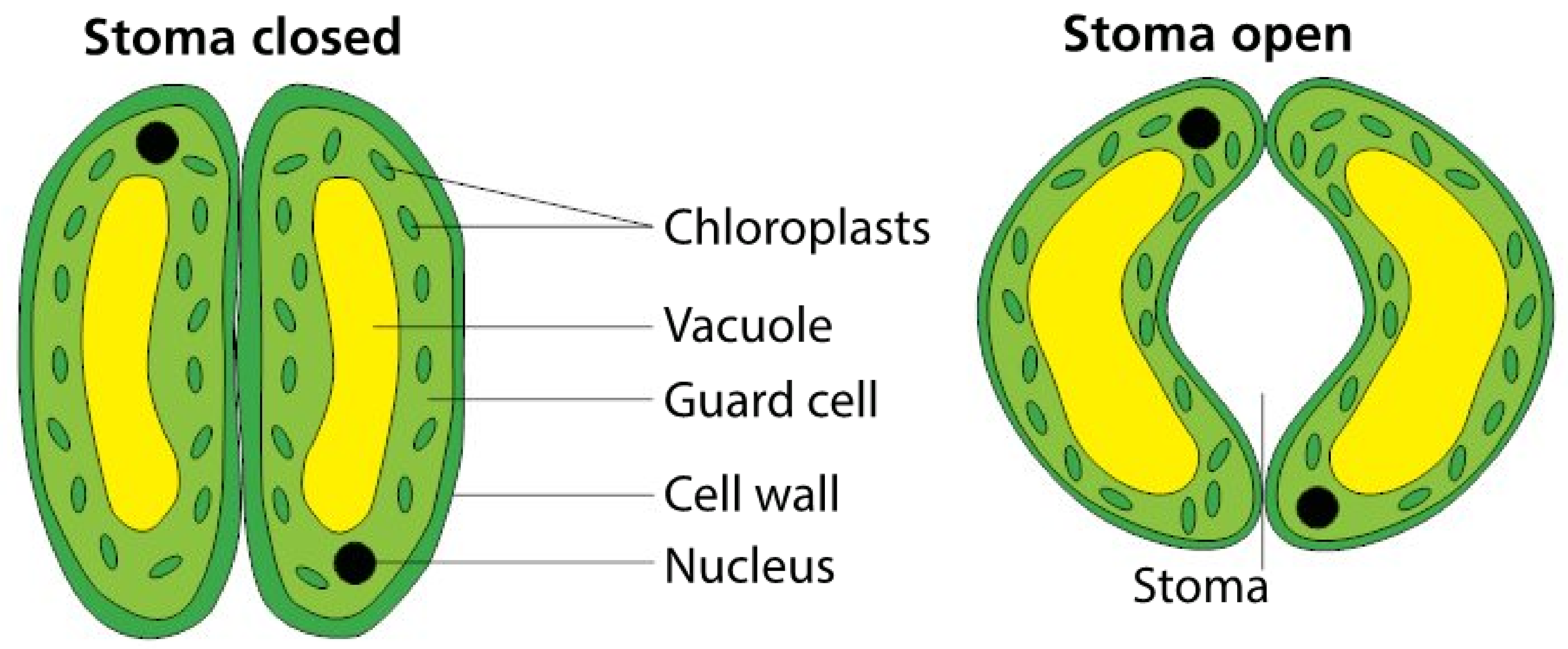
There are three phases in aerobic respiration that are involved in turning glucose into energy: glycolysis, the **Krebs cycle** and the **electron transport chain**.

WHAT IS ANAEROBIC RESPIRATION?

Most cells are able to generate ATP in the absence of oxygen for a very short amount of time. Any form of cellular respiration where oxygen is not required is called anaerobic respiration. Most cells resort to anaerobic respiration when the supply of oxygen is low, but some organisms *only* obtain their energy anaerobically. Find out more about the products of anaerobic respiration in animals and plants and compare them with those of aerobic respiration.

DISCUSS

The opening and closing of the stoma (plural: stomata) depend on the amount of water that moves in and out of the guard cells through **osmosis**; this causes changes of pressure called **turgor**. Look at Figure 5.38. What happens when more water moves into the cells? Apart from O_2 and CO_2, what else could the stomata control? At what time of the day do you think the stomata are open? What will happen if the stomata are permanently open?



■ **Figure 5.38** Diagram of a closed and open stoma

HOW DO ORGANISMS DEPEND ON WHAT THEY EXCHANGE WITH THEIR ENVIRONMENT?

How do living things exchange gases with their environment?

We saw earlier in this chapter how living things rely on their environment to obtain and transform energy in its many forms. This involves complex chemical reactions that require key gases such as oxygen (O_2) and carbon dioxide (CO_2) to be exchanged between their cells and the environment. **Gas exchange** is, therefore, the process by which O_2 is taken in and CO_2 is removed (and vice versa in the case of plants).

Plants, animals and unicellular organisms have different ways of doing this but it all happens through a gas exchange surface. We will look into that in more detail in this section.

Gas exchange in plants

We have looked closely at the structures and processes that enable plants to carry out photosynthesis at the cellular level. Let's zoom out and look at the bigger structures that allow plants to exchange gases with the environment so that they are able to reach the cells.

ACTIVITY: A tour inside a plant leaf!

ATL

- Communication skills: Organize and depict information logically
- Critical-thinking skills: Practise observing carefully

Carefully observe Figure 5.39. You can see different layers of cells in a section of a leaf as you move from the upper side to the lower side. From the list of functions provided below, **identify** which structure is adapted to which function and what aspect of its form enables this to happen. Use a table to present your answers.

List of functions

A **Transports water and minerals to the leaves. Transports products of photosynthesis to other parts of the plant. Supports the leaf.**

B **Allows gas exchange between the leaf and the atmosphere.**

C **Absorbs light and performs photosynthesis.**

D **Regulates and controls exchange of CO_2 and O_2 with the environment. Prevents water loss and protects the leaf.**

List of enabling structures/forms

E **Specialized tissues (xylem and phloem)**

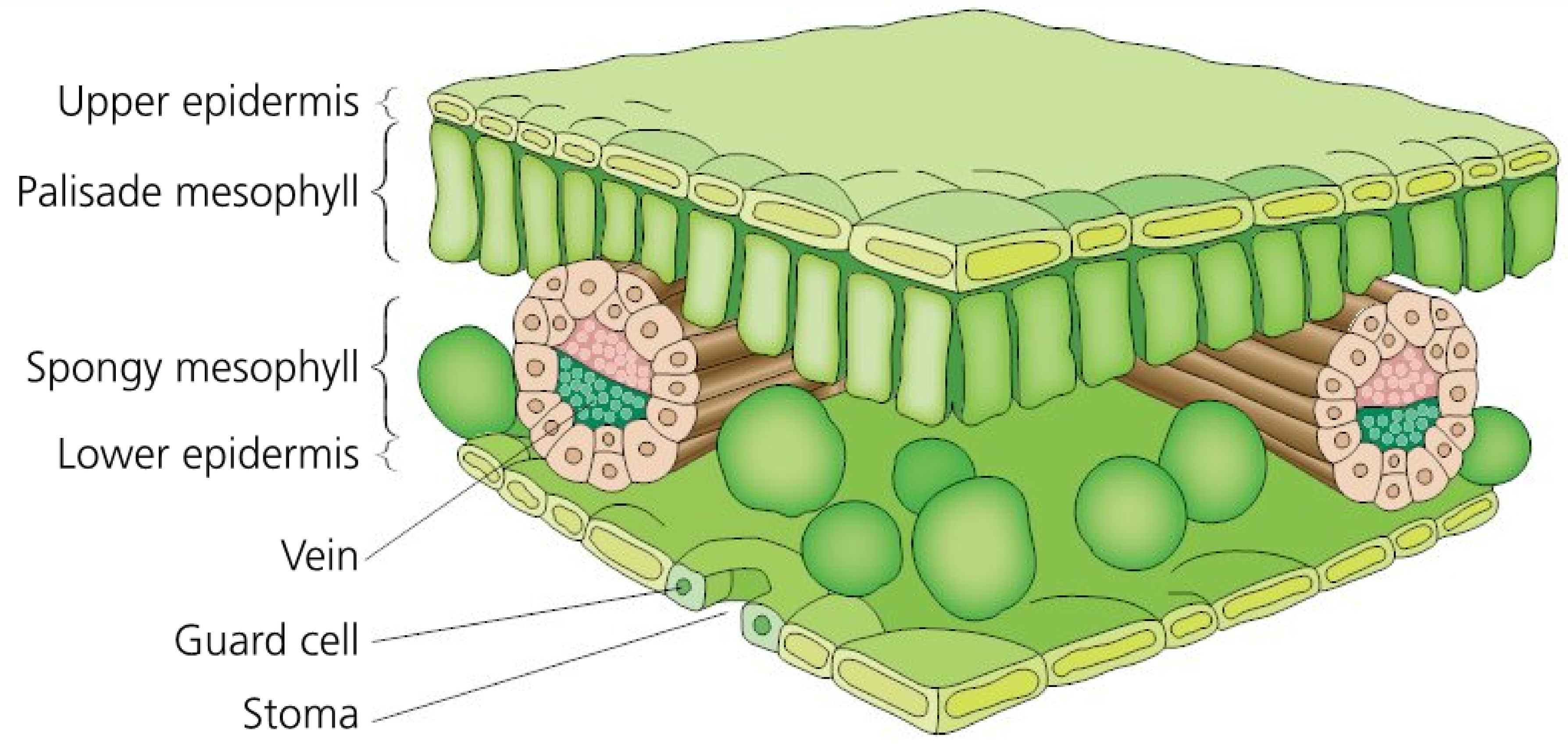
F **Cells are loosely packed allowing air pockets for gases to flow inside the leaf (just like a sponge!); contain few chloroplasts**

G **Layers of packed cylindrical cells full of chloroplasts**

H **Contains stomata and a waxy cuticle**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.



■ **Figure 5.39** Diagram of a leaf structure

WHAT MAKES YOU SAY THAT?

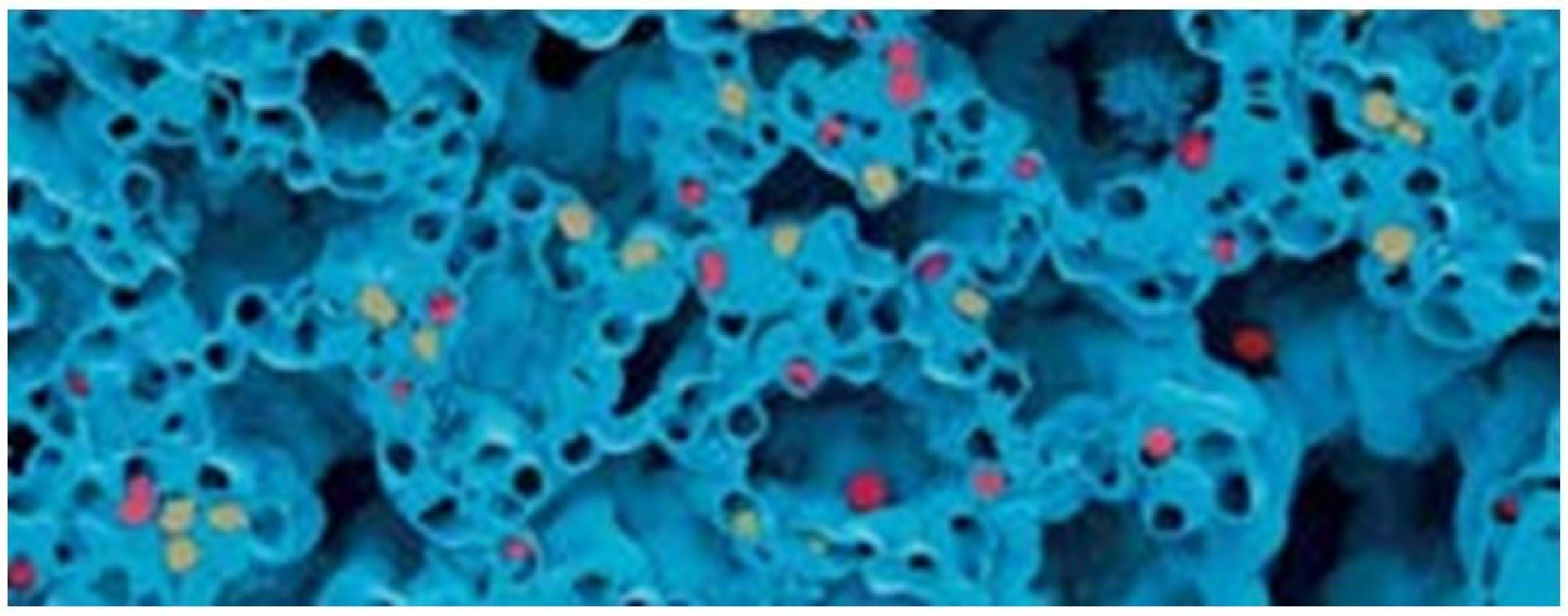
Look at Figures 5.39 and 5.41. In which way are the **alveoli** in the lungs similar to the spongy mesophyll layers in the plant leaf? What connections or similarities can you think of? What makes you say that?

EXTENSION

Any living cell exchanges water with its environment via a process called **osmosis**. Substances such as minerals and gases are exchanged through diffusion (see earlier this chapter). Search **osmosis, semipermeable membrane** in your browser to find out more about these two important processes and then prepare a table in which you compare them. Once done, find out how macromolecules are exchanged between a cell and its environment (consider amoeba and excretory cells as examples).

GAS EXCHANGE IN ANIMALS

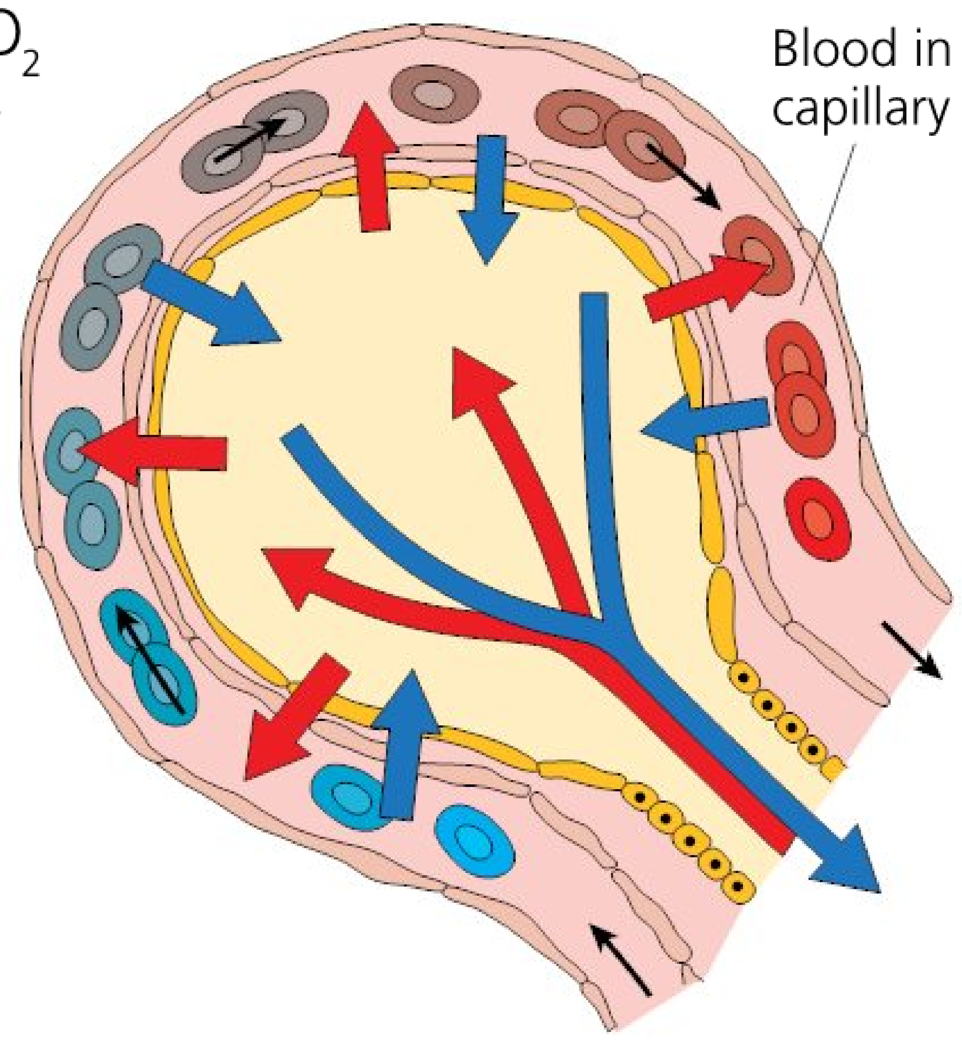
■ **Figure 5.40** Close-up of the gills of a perch. Gills are the major site of gas exchange in fish.

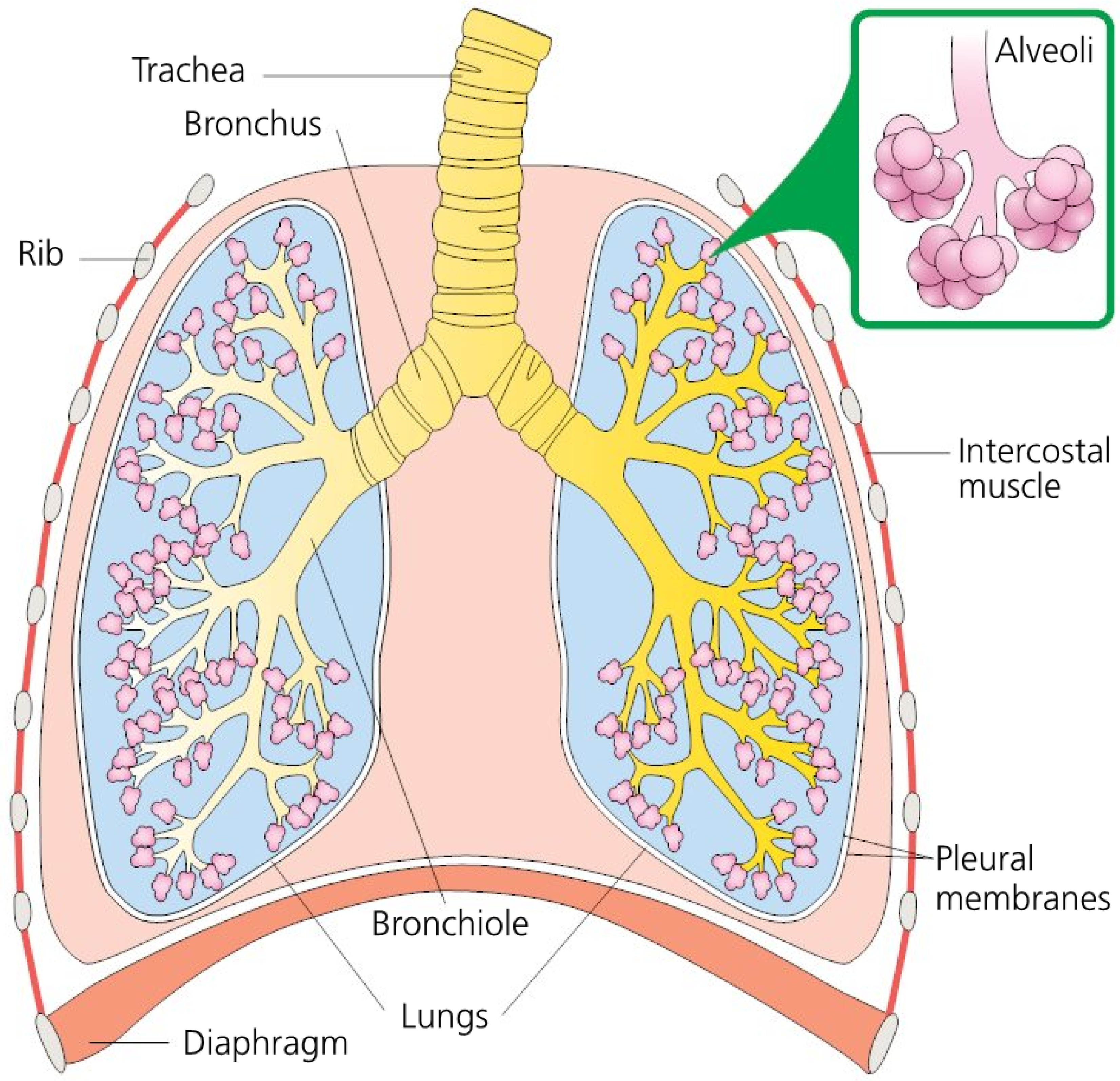


■ **Figure 5.41** Coloured scanning electron micrograph (SEM) of alveoli in a human lung. Each alveolus is a site for gas exchange between the air in the air sac and the blood in nearby capillaries.

Case study: the human respiratory system

Cells in the human body (as well as those in other mammals) need a continual and efficient supply of oxygen to maintain a constant body temperature and perform all the necessary metabolic functions for survival. A lack of oxygen to a cell can be fatal if it lasts longer than few minutes. Cells also need to get rid of CO_2 quickly. The human body is equipped with a **ventilation** system that ensures adequate levels of gas exchange. The respiratory system comprises all the structures that allow this process to be as efficient as possible.





■ **Figure 5.42** The human respiratory system and a close-up of an alveolus showing gas exchange

ACTIVITY: In and out!

ATL

- Critical-thinking skills: Analyse complex concepts into their constituent parts and synthesize them to create new understanding; Interpret data

1. **Examine the diagram in Figure 5.43 then, in pairs, rearrange the steps in Table 5.3 by numbering them in order to describe the mechanical processes of inhaling (breathing in) and exhaling (breathing out).**
2. **Table 5.4 shows the composition of air (values are approximate). Determine which column represents the composition of inhaled air and which one represents exhaled air. Justify your answer.**
3. **Figure 5.44 shows the apparatus for an experiment used to test inhaled and exhaled air. The test tubes contain lime water, $Ca(OH)_2$. Apply what you have learnt about the products of human respiration to suggest what might be observed in this experiment.**

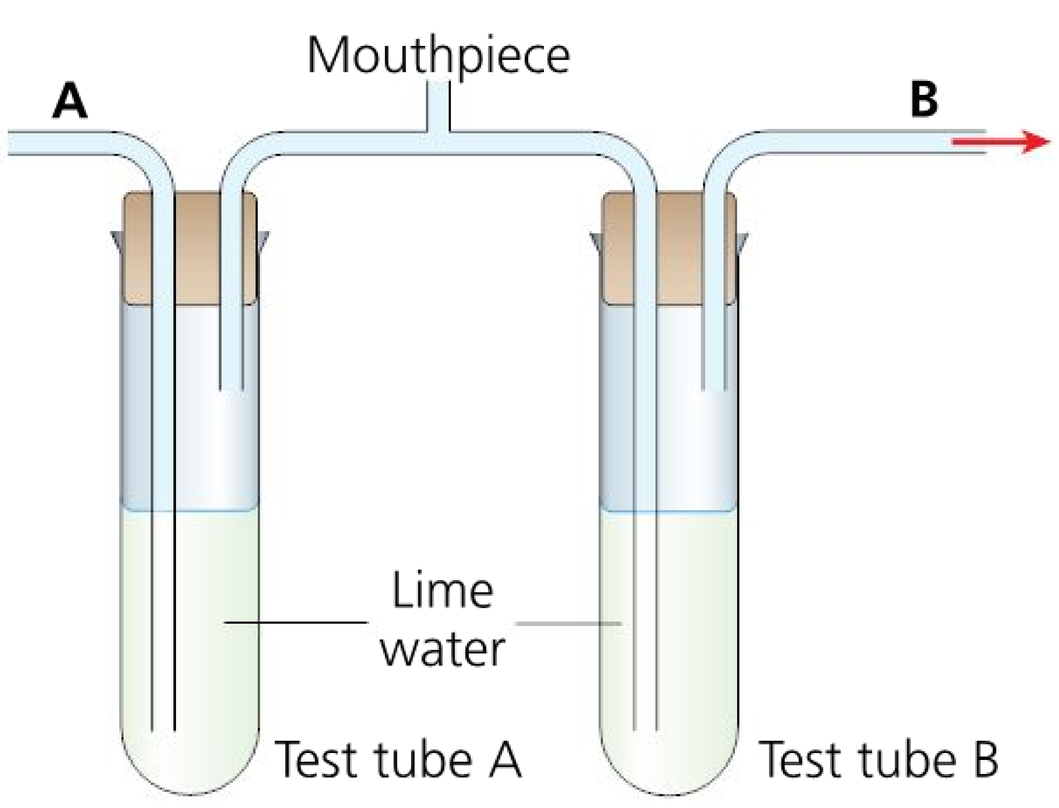


Figure 5.44 Apparatus to test presence of CO_2 in inhaled and exhaled air

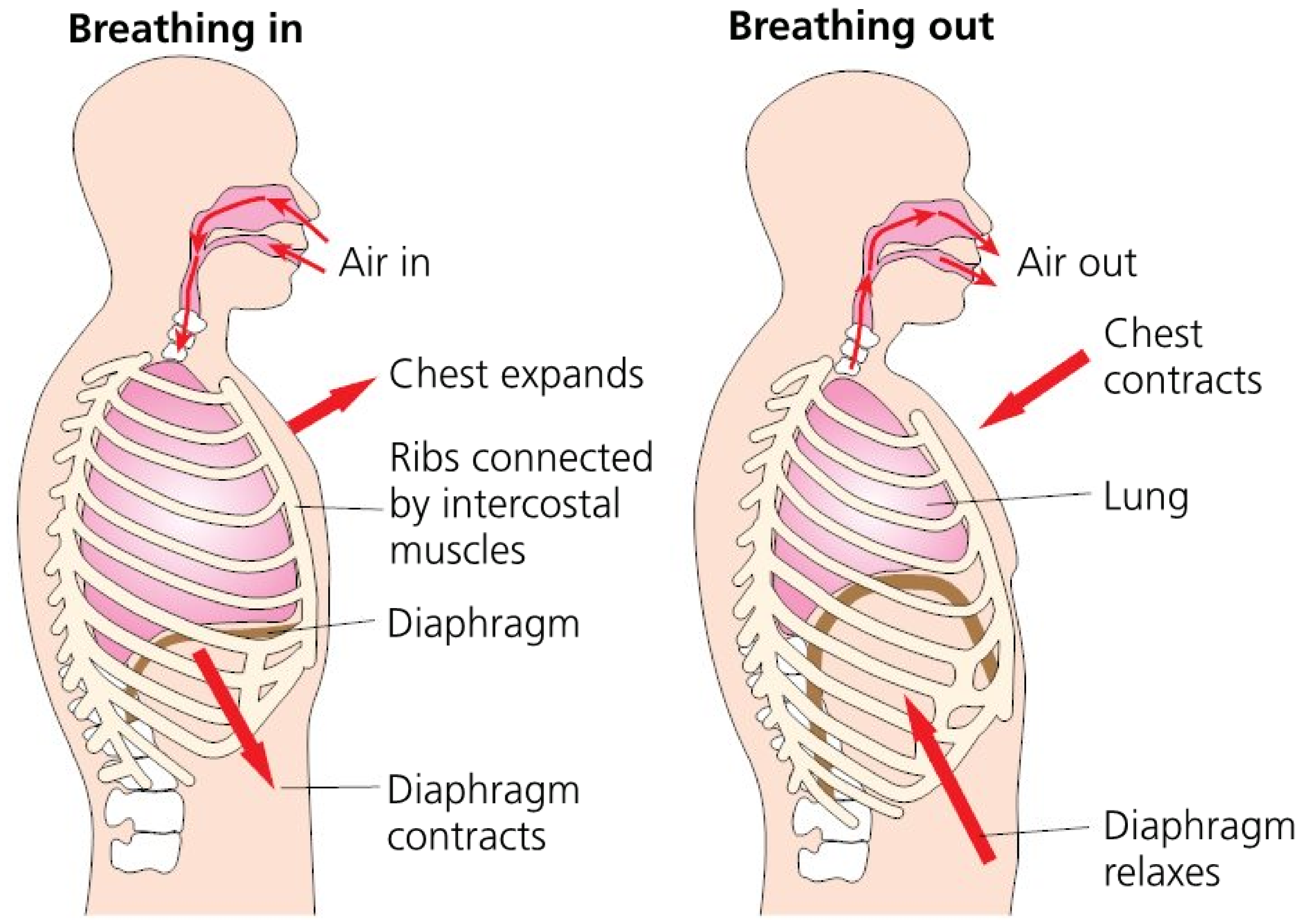


Figure 5.43 The movement of the chest during breathing

Breathing in (inhalation) steps	Breathing out (exhalation) steps
Air is forced down through the trachea into the lungs. ☐	Air is forced up out through the trachea and out of the mouth. ☐
At the same time the intercostal muscles contract and move the ribcage up and out. ☐	Diaphragm relaxes and moves upwards. ☐
The increase in volume causes the pressure to drop. ☐	The decrease in volume causes the pressure to rise. ☐
The volume inside the thorax (chest) increases. ☐	At the same time the intercostal muscles relax and the ribcage falls down and inwards. ☐
Diaphragm contracts and moves downwards. ☐	The volume inside the thorax (chest) decreases. ☐
The pressure in the chest is lower than the atmospheric pressure outside. ☐	The pressure in the chest is higher than the atmospheric pressure outside. ☐

Table 5.3 Steps involved in inhalation and exhalation

Component of air	?	?
nitrogen (N_2)	78%	78%
oxygen (O_2)	21%	16%
carbon dioxide (CO_2)	0.04%	4%
other gases including water vapour	0.96%	2%

Table 5.4 Comparing composition of inhaled and exhaled air

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding and Criterion C: Processing and evaluating.

Does nature ever waste energy?

ACTIVITY: The dream of perpetual motion

ATL

- Critical-thinking skills: Evaluate evidence and arguments; Develop contrary or opposing arguments

Before the physics of work and efficiency was first elaborated in the early nineteenth century CE, many people had pondered whether it would be possible to make a machine that would run forever once it had been started with an initial input of energy. These machines were called **perpetual motion machines**.

Search **perpetual motion machines** to find out about some of the designs that were suggested for such machines. **Summarize** the hypothesis behind perpetual motion. Choose one such proposed machine and **analyse** why it cannot work. **Explain** why no perpetual motion machines can ever work, with reference to the **laws of thermodynamics**.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

We have seen that in all machines and processes, without exception, some of the energy provided is lost, usually as heat. Sound is another way in which a machine can lose energy. The energy is considered to be 'wasted' because once it has been emitted into the environment, there is no way we can get it back to use it again.

The amount of useful work done compared to the total energy input gives us the **efficiency** of the machine:

$$\text{efficiency, } e = \frac{W_{out}(\text{J})}{E_{in}}$$

ACTIVITY: Efficient or not?

ATL

- Information literacy skills: Access information to be informed and inform others
- Critical-thinking skills: Interpret data

Table 5.5 shows some typical efficiency values of common machines or devices.

Machine or process	Typical efficiency *e*/% (approximate)
human walking	25%
bicycle	90%
internal combustion engine (petroleum)	25%
electric motor	50%
electromagnetic transformer	90–97%

Table 5.5 Typical efficiencies

Interpret the data. Decide on three categories for a machine: high, medium and low efficiency. Categorize the machines accordingly.

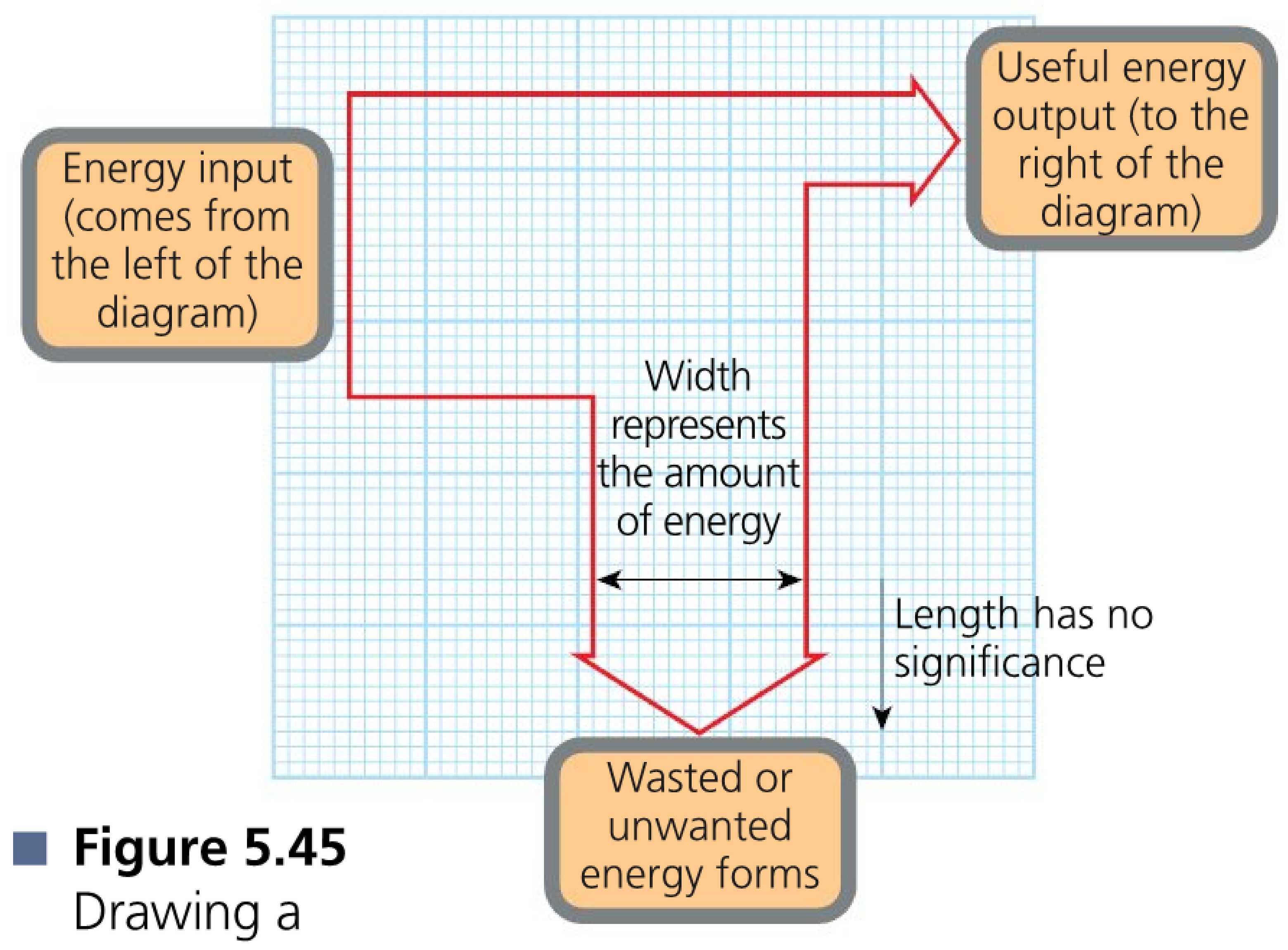
Research how each of the machines works. Share your findings with other groups.

As a class, **summarize** the common features shared by the machines in each category. What do you think makes the least efficient ones so inefficient and the most efficient ones so efficient?

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

Since efficiency is a ratio, it has no unit. Since W_{out} is *always* less than E_{in}, efficiency always has a value between 0 and 1 ($0 < e < 1$). It is often expressed as a percentage; just multiply by 100. The more efficient a machine or process, the better.



■ **Figure 5.45** Drawing a Sankey diagram

REPRESENTING ENERGY CHANGE

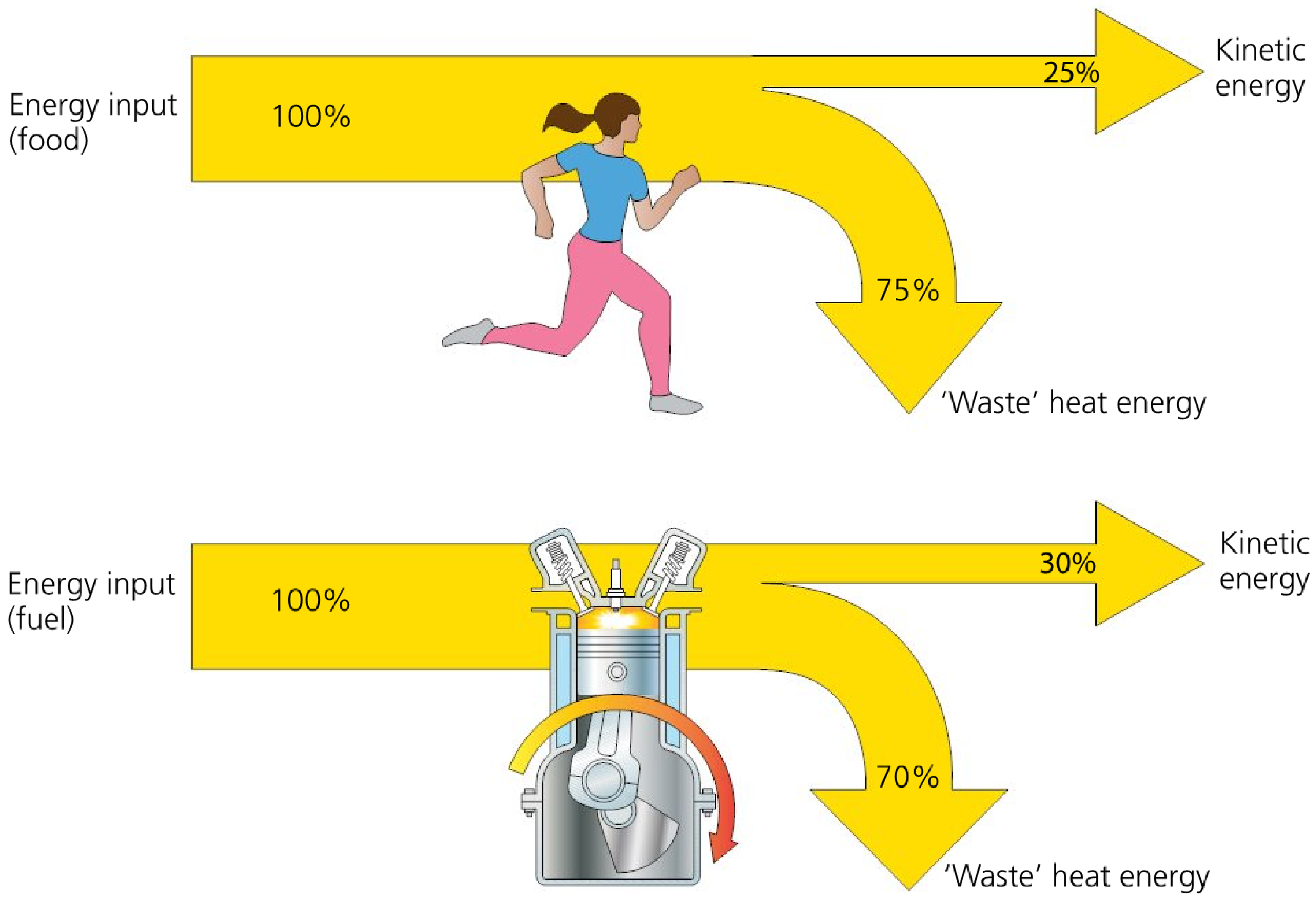
A common way to present energy changes in a system or process is a **Sankey diagram** (Figure 5.45). There are some variations in the way these are drawn, but generally:

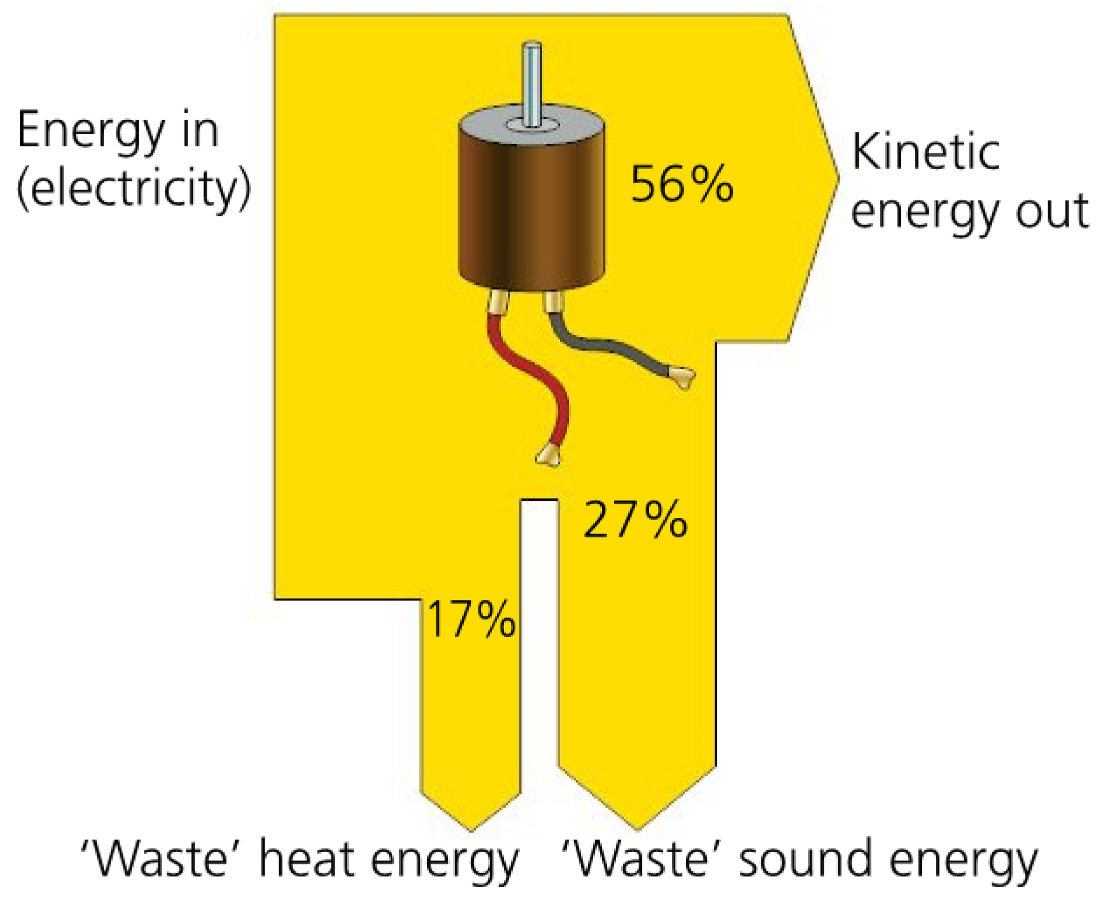
- the 'flow' of energy through the process is shown using arrows, going left to right
- the input of energy is shown on the left
- the 'useful' output of energy or work is shown on the right
- wasted energy is shown leaving the system either upward or downward
- the width of the arrows is proportional to the percentage of energy in that form.

Figure 5.46 shows how we can draw some of the systems from Table 5.5 using Sankey diagrams.

EXTENSION

The efficiency values for the human body can be misleading when compared to those of a mechanical machine. Organisms require energy to function even when not exercising, so their energy consumption can be higher and the calculated output then depends on whether or not this 'basal' consumption is considered as work. Search **Harris–Benedict equation** and **basal metabolic rate** to find out more.

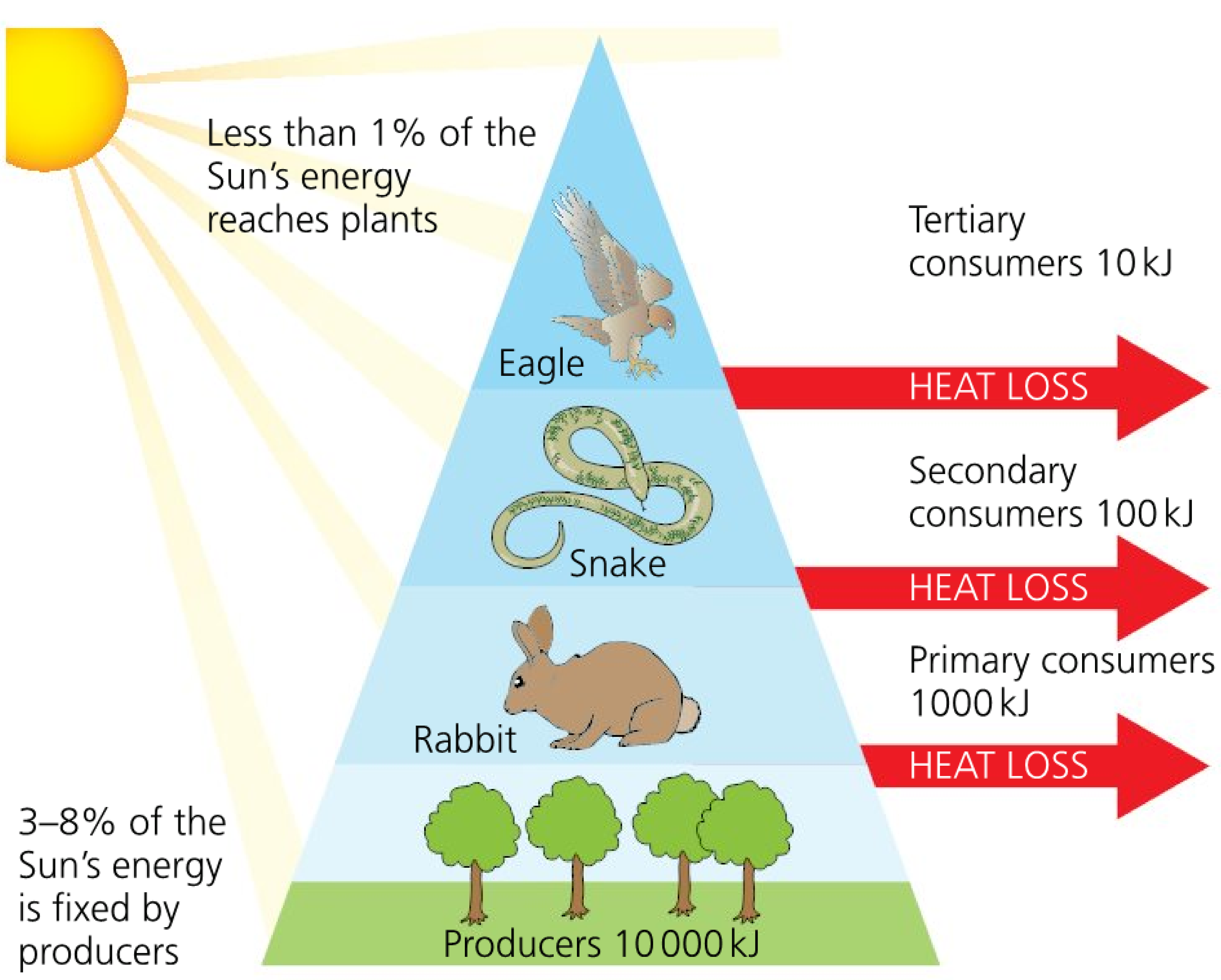




■ **Figure 5.46** Sankey diagrams for natural and artificial processes

HOW DOES ENERGY FLOW IN ECOSYSTEMS?

In every ecosystem, energy is transferred along food chains from one **trophic level** to the next (see Figure 5.47 and Chapter 11 for more on food chains). A plant uses the Sun's energy to make organic molecules to build **biomass** which serves as food for the next consumer. Another part of the energy is spent on other necessary functions such as reproduction and transport. The cost is energy lost in the form of heat as a result of cellular respiratory metabolism. In turn, primary consumers that feed on plant biomass use the energy locked in the organic molecules to grow and make their own biomass which is fed on by the next consumers in the chain. They also need energy to reproduce and respire and move. Energy is lost again in the form of heat from respiration and waste (**egestion**). This process happens at each trophic level, such that the amount of energy available to the next trophic level decreases. Scientists suggest that the percentage of energy transferred from one trophic level to another ranges between 5 per cent and 20 per cent of the total energy acquired from the previous level. An average value of 10 per cent is often used to describe the **ecological efficiency** of energy transfer in ecosystems in general.



■ **Figure 5.47** Ecological efficiency through a food chain

ACTIVITY: How efficient are organisms at using the energy available to them?

ATL

- Critical-thinking skills: Analyse complex concepts and projects into their constituent parts and synthesize them to create new understanding

Look at Figure 5.47.

1. **Assuming the percentage of solar energy fixed by plants is 7 per cent of the total amount falling on leaves, calculate the total amount of solar energy falling on the leaves in this food chain (in kJ).**
2. **Solar panels convert 6–20 per cent of solar energy; some manufacturers are able to make even more efficient ones. Compare the efficiency of plants and solar panels.**
3. **Calculate the amount of solar energy (in kJ) that is fixed by producers in this food chain and used to produce 10 000 kJ of plant biomass.**
4. **Calculate the amount of energy (in kJ) that was lost and did not contribute to building biomass in the producers.**
5. **In each trophic level in the diagram, show the amount of energy available as biomass to the next level in the form of a percentage of the initial value available in producers (instead of a value in kJ).**
6. **Explain why food chains have no more than 4–5 trophic levels.**
7. **Decomposers live on organic matter from dead plants and animals. Adapt the diagram in Figure 5.47 to show how energy flows from producers and consumers to decomposers in this food chain.**
8. **Is it more energy efficient for secondary consumers to eat other animals or plants? Justify your answer using scientific reasoning.**

Based on your conclusion from this activity, what answers can you **suggest** for our debatable question: 'Does nature ever waste energy?' **Organize** a small class discussion to answer this question and use your understanding from this activity to support your arguments.

◆ Assessment opportunities

- ◆ In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

ACTIVITY: Reflecting on energy change, forms and processes

ATL

- Reflection skills: Consider content
- Information literacy skills: Make connections between various sources of information
- Critical-thinking skills: Revise understanding based on new information and evidence

Elaborate the energy flow diagram from the start of the chapter (Figure 5.1) to show the *forms* of energy at each stage and the *processes* that convert energy from one form to another.

Can you now elaborate the connections further to show other changes taking place?

In this chapter we have explored how the concept of energy allows us to analyse and understand natural processes and use them to inspire better and more sustainable solutions. In the following activities you will be asked to use the understanding you have gained from this inquiry to initiate two service learning projects.

! Take action: The future of the automobile

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument; Consider ideas from multiple perspectives; Propose and evaluate a variety of solutions
- Information literacy skills: Access information to be informed and inform others; Collect and analyse data to identify solutions and make informed decisions

! Your school needs a new minibus to transport the sports teams to events and would like to make a decision that is sustainable and 'future-proof'. They are considering whether to buy a gasoline, diesel, electric or hybrid vehicle.

! An electric vehicle (or EV) uses only an electric motor and an on-board battery that needs to be charged.

! A hybrid vehicle (or HV) has both an electric motor and a small on-board diesel or gasoline engine. The conventional engine is used to generate electricity to charge the battery.

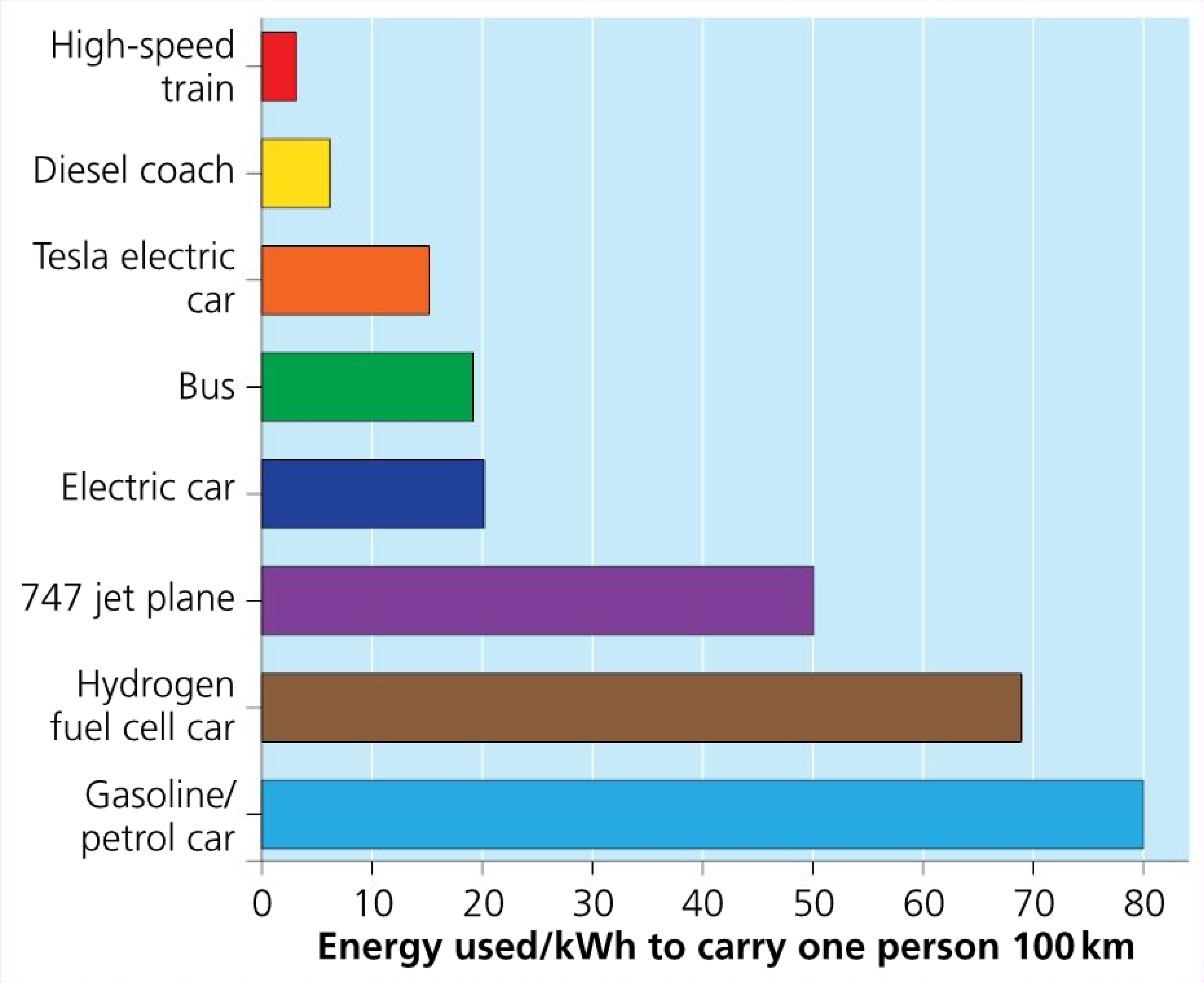
! Many EVs and HVs also have 'brake regeneration', a system which recycles the kinetic energy lost on braking and uses it to charge the battery by using the electric motor in reverse as a generator.

! In pairs: before beginning this activity, actively read these articles. Each partner should read one of the two suggested. Make notes or highlight key points.

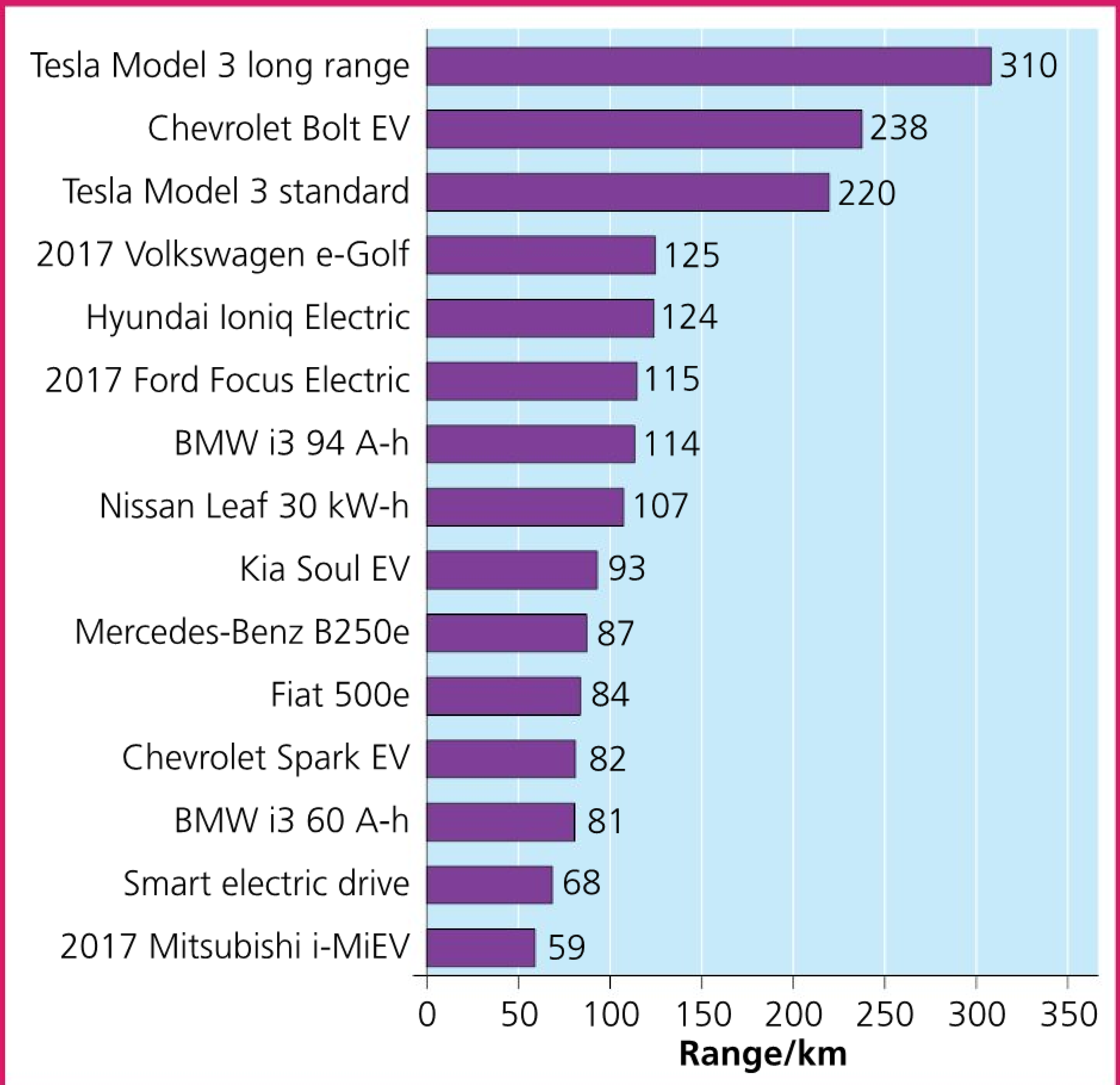
1. **Either: www.nytimes.com/2017/07/06/business/energy-environment/france-cars-ban-gas-diesel.html**
   or: www.theguardian.com/politics/2017/jul/25/britain-to-ban-sale-of-all-diesel-and-petrol-cars-and-vans-from-2040
2. **Either: www.telegraph.co.uk/cars/features/electric-car-drivers-could-face-queues-quarrels-christmas/**
   or: www.theguardian.com/environment/2017/aug/04/fewer-cars-not-electric-cars-beat-air-pollution-says-top-uk-adviser-prof-frank-kelly

! On the following pages are some infographics, data tables and excerpts from online blogs about electric and hybrid vehicles. Using this information, and your own research, **write** a report on either electric or hybrid vehicles, in which you **compare** and **evaluate** with conventional diesel/gasoline vehicles. Make sure that you **explain** the science and the technology of your chosen type of vehicle. Be sure to **summarize** the engineering challenges that have been solved and those that still need to be solved. **Discuss** and **evaluate** a number of the implications of transferring to this kind of vehicle – both specifically for the school, but also for society as a whole. In the **conclusion** of your report, make a recommendation to the school about whether your chosen kind of vehicle is a good option or not.

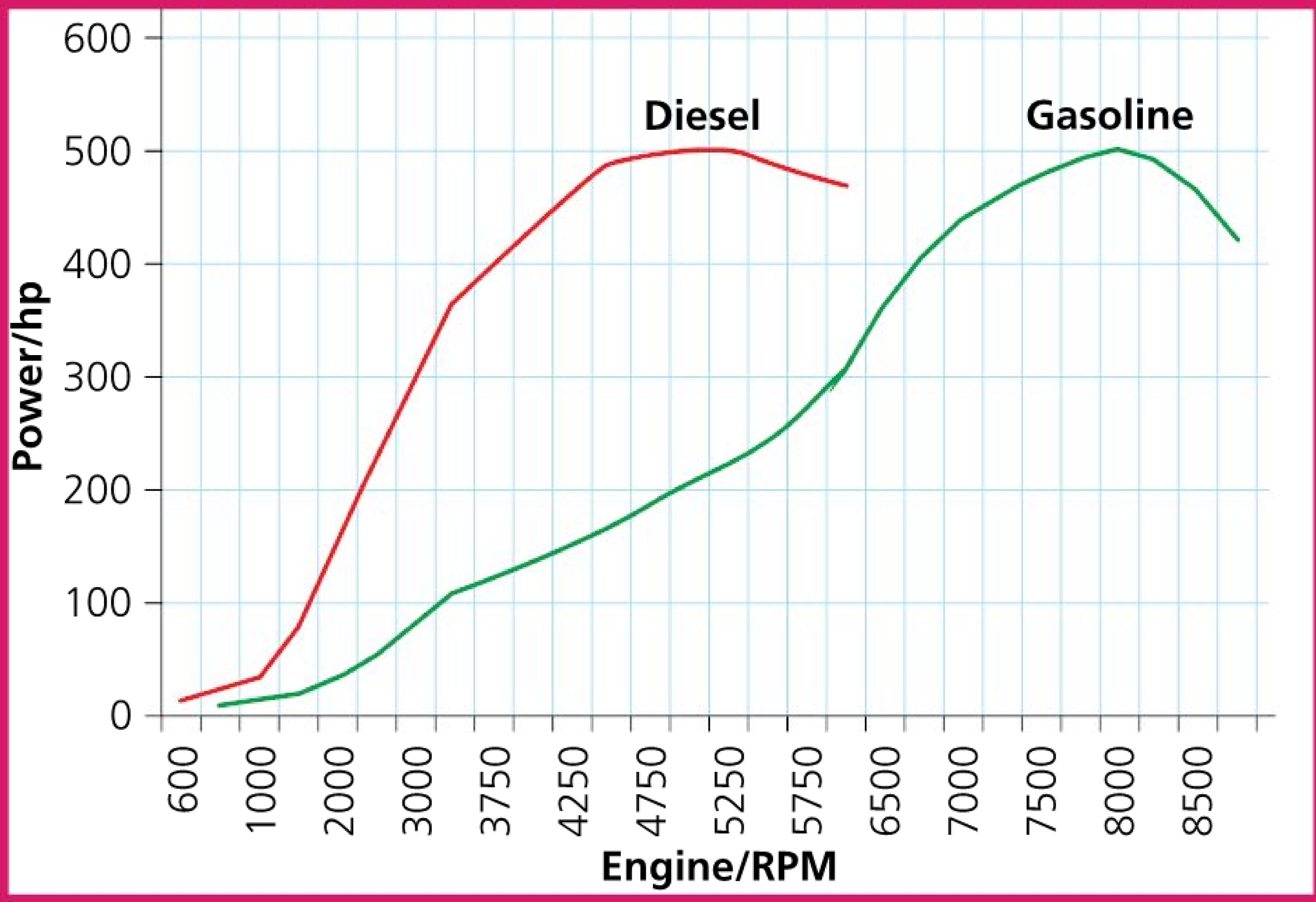
! Use the scientific terminology you have learnt in this chapter clearly and precisely; be sure to **document** all your sources in line with your school's policy on referencing and academic integrity.



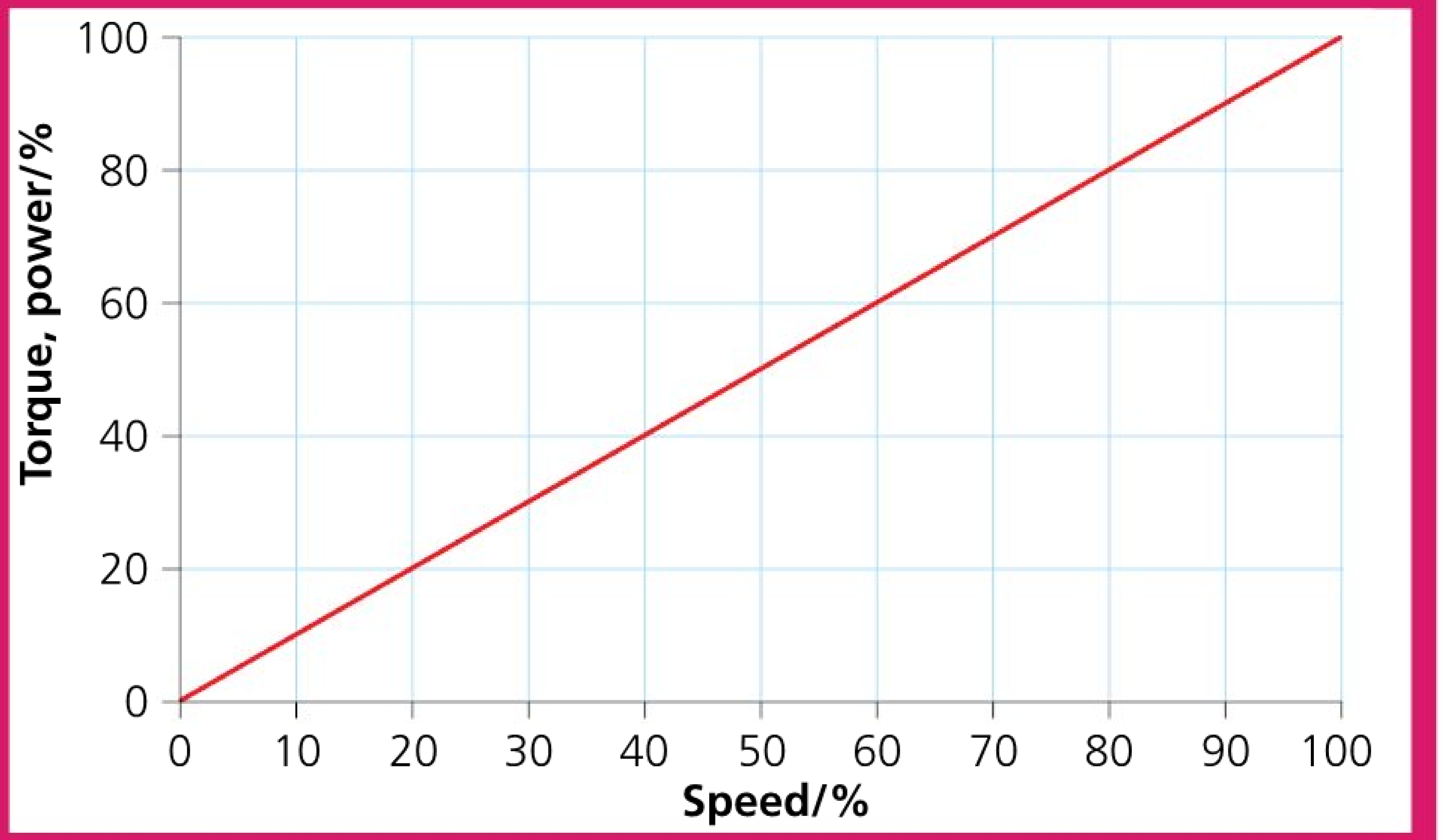
■ **Figure 5.48** Energy used to carry one person 100 km for different vehicles. Data source: *Sustainable energy without the hot air* by David MacKay (**www.withouthotair.com**)



■ **Figure 5.49** Ranges for a full charge for some electric vehicles (EVs) available in the US market. Data source: Mariordo (Mario Roberto Durán Ortiz)



■ **Figure 5.50** Power output with engine revolutions per minute (RPM) for conventional engines



■ **Figure 5.51** Power output with speed for electric motor

◆ Assessment opportunities

◆ This activity can be assessed using Criterion D: Reflecting on the impacts of science.

SOME REVIEW PROBLEMS TO TRY

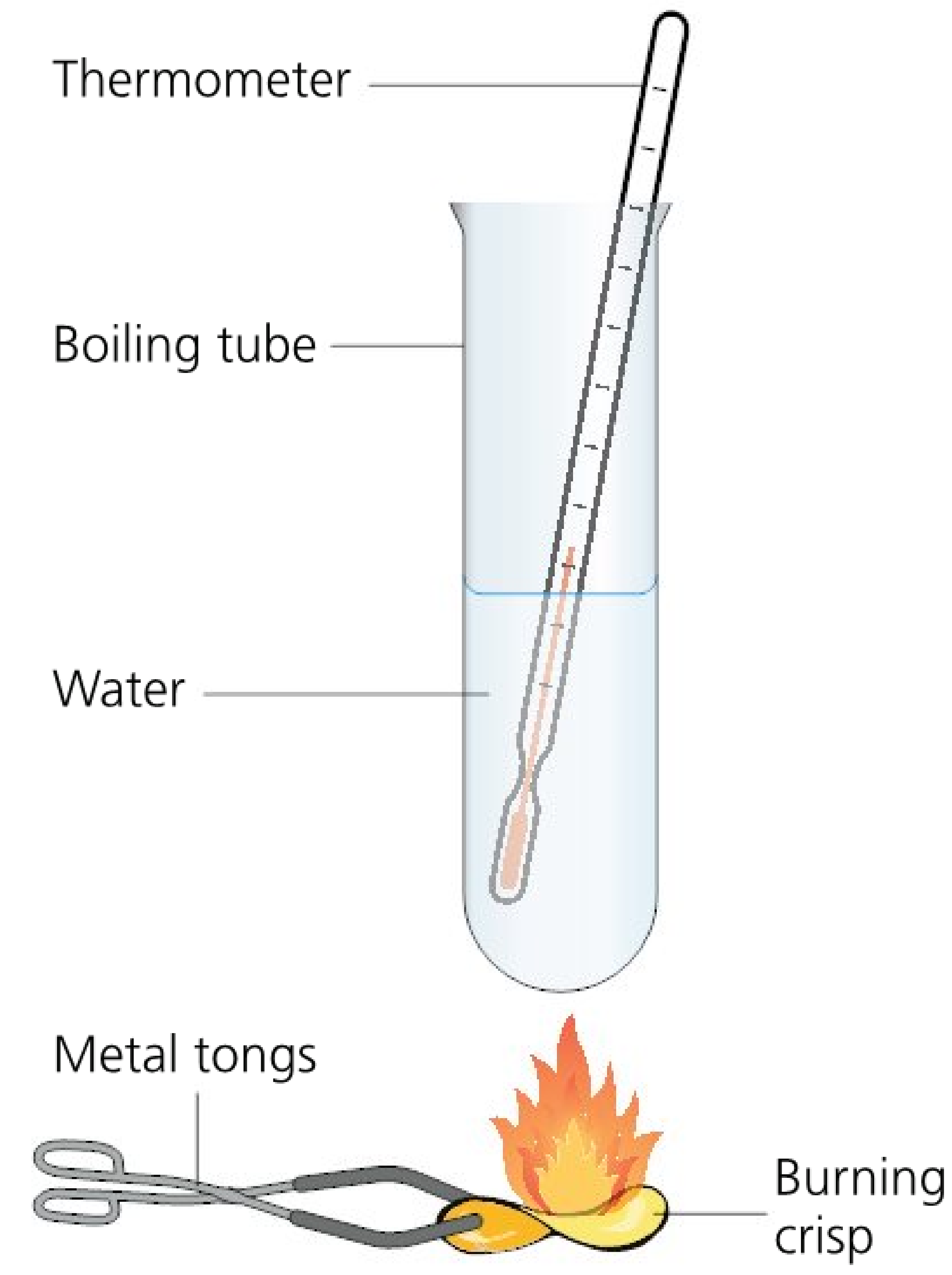


Figure 5.52 An experiment to measure the amount of energy stored in food

1 A student wanted to measure the energy stored in crisps and compare it to the value displayed on the actual packaging. He set up the apparatus shown in Figure 5.52.
Before starting the experiment, the student weighed the crisp and the water used in the boiling tube and recorded the temperature of the water. After burning the crisp completely, he recorded the temperature rise and used the following formula to calculate the energy released from the burnt crisp (in joules per g of crisp):

$$\text{energy released from food per gram (J)} = \frac{\text{(mass of water (g)} \times \text{temperature rise (°C)} \times 4.2)}{\text{(mass of food sample (g))}}$$

His results are shown in Table 5.6.

Average energy released/ J/g	Average energy released/kJ per 100 g	Energy content as displayed on the packaging of the crisps/kJ per 100 g
15 000	?	2200

Table 5.6 Results of the burning crisps experiment

a **Calculate** the value of the average energy released in order to convert the unit from joules per g (J/g) to kilojoules per 100 g (kJ/100 g). Write your answer in the second column of the table.

b **State** why it is necessary to use the unit kJ per 100 g instead of J/g.

c **Compare** the energy released from the burnt crisp in this experiment with that displayed on the packaging. What do you notice?

d **Suggest** a possible **explanation** for the difference in the energy content between the experimental result and that displayed by the crisps manufacturer.

e **Evaluate** the method used in this experiment and **suggest** improvements for more accurate results.

2 The Gravity Light Foundation is developing a range of electric lights that use gravity rather than fossil fuels such as kerosene to produce light sustainably. Look at their website (**https://gravitylight.org/**) and review how it works using the menu in the top right of the site.

a **Explain** the science behind the design of the light with reference to what you have learnt in this chapter.

b From the website, **collect** information on the design of the light, for example the mass used to power the light, the length of its drop and the time taken for the drop.

c Using this information, **calculate** the power generated in the light.

d **Outline** how the power generated for the light might change as the mass falls under gravity. **Evaluate** how this might affect the output from the light.

3 Table 5.7 shows a number of substances that can be used as fuels and their enthalpies of combustion. The enthalpy of combustion of a reaction is the energy given out when one mole of a substance is burnt in excess oxygen.

Fuel name	Fuel formula	Enthalpy of combustion/kJ mol^{-1}	RFM (relative formula mass of fuel)	Energy released when 1 g of fuel is burnt/kJ g^{-1}
hydrogen		286		
methane		891		
coal (carbon)		394		
methanol	CH_3OH	726	12 + (3 × 1) + 16 + 1 = 32	
ethanol	C_2H_5OH	1367		
octane		5470		
glucose		2803		

■ **Table 5.7**

a **State** the formulae of the remaining fuels in the column 'Fuel formula'.

b **Deduce** the relative formula mass of each fuel, using the methanol example that has been completed for you.

c **Calculate** the energy released for 1 g of each fuel burnt.

d **Draw** a graph of fuel energy released when 1 g fuel is burnt against fuel name.

e **Analyse** the graph.

f **Formulate** balanced symbol equations with state symbols for the combustion of hydrogen, coal, methanol and octane.

g Octane, a liquid at room temperature, is the main component of petrol in cars and is produced during the fractional distillation of crude oil. Hydrogen, a gas at room temperature, is an alternative fuel that could be used in car engines that have been developed for this purpose. **Analyse** and **evaluate** the information above and in the table and use your additional knowledge, including the properties that a good fuel will have, in order to make a scientifically informed judgment about which fuel should be used in cars.

Reflection

In this chapter we have **classified** energy in various ways, according to its form and the processes by which it interacts with matter. We have **explained** the relationship between force and energy and **discussed** how this affects motion of objects in terms of the work done and the power. We have **explained** how efficiency can be calculated and **discussed** the natural limit on efficiency for any machine or process.

We have **described** different types of chemical reactions, focusing on combustion reactions on which we rely for energy. We have **explained** the difference between endothermic and exothermic reactions and **analysed** energy level diagrams. We have **outlined** how fossil fuels are formed, **evaluated** the impacts of their extraction and **identified** the products formed in their combustion. We have **described** the fractional distillation process on a small scale within the laboratory and on a large scale looking at crude oil.

We have **described** the function of enzymes in controlling the energetics of important biochemical reactions and **discussed** how enzyme properties can be used to improve our lives. We have **summarized** how energy gets transformed and transferred in living cells and between different living organisms in ecosystems. We have **explained** the importance of gas exchange to the energetic processes of cells and organisms and we have **outlined** the connection between the micro and macro levels. We have learnt how to **calculate** the energy efficiency in different trophic levels.

<table>
<tr><th colspan="6">Use this table to reflect on your own learning in this chapter</th></tr>
<tr><td>Questions we asked</td><td>Answers we found</td><td colspan="4">Any further questions now?</td></tr>
<tr><td>Factual</td><td></td><td colspan="4"></td></tr>
<tr><td>Conceptual</td><td></td><td colspan="4"></td></tr>
<tr><td>Debatable</td><td></td><td colspan="4"></td></tr>
<tr><td rowspan="2">Approaches to learning you used in this chapter</td><td rowspan="2">Description – what new skills did you learn?</td><td colspan="4">How well did you master the skills?</td></tr>
<tr><td>Novice</td><td>Learner</td><td>Practitioner</td><td>Expert</td></tr>
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<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Learner profile attribute(s)</td><td colspan="5">Reflect on the importance of being knowledgeable for your learning in this chapter</td></tr>
<tr><td>Knowledgeable</td><td colspan="5"></td></tr>
</table>

Systems | Balance; Environment | Fairness and development

6 How do different chemical environments support life?

If healthy lives are to be enjoyed **by all**, we must understand the fine **balance** of chemical **systems** both inside our bodies and with our **environment**.

CONSIDER THESE QUESTIONS:

Factual: What is the difference between an acid and a base? How do acids react? How do we make salts? How do organisms maintain balance when adapting to changes inside and outside the body?

Conceptual: How does form meet function in the digestive system? Why does pH matter to us?

Debatable: Are modern medical advances and diagnostic methods accessible to all?

Now **share and compare** your thoughts and ideas with your partner or with the whole class.

■ **Figure 6.1** What is the chemical balance in these dishes?

IN THIS CHAPTER, WE WILL …

- **Find out** how acids and bases react and produce new substances, and how their properties determine the taste and nutritional value of foods.
- **Explore** how to predict the properties of the substances produced in reactions between acids and bases, and how those reactions enable us to digest food for healthy living.
- **Take action** to understand and raise awareness of differences in access to medical procedures in different parts of the world and of the diseases that can be caused through inadequate and unbalanced nutrition.

These Approaches to Learning (ATL) skills will be useful …

- Reflection skills
- Critical-thinking skills
- Information literacy skills
- Collaboration skills
- Communication skills
- Creative-thinking skills
- Transfer skills

Assessment opportunities in this chapter:

The activities in this chapter will help you develop and evaluate your learning in these MYP Sciences learning objectives:

- **Criterion A:** Knowing and understanding
- **Criterion B:** Inquiring and designing
- **Criterion C:** Processing and evaluating
- **Criterion D:** Reflecting on the impacts of science

KEY WORDS

digest
dissolve
equilibrium
excrete
metabolism
neutralize
reversible

We will reflect on this learner profile attribute …

- Balanced – we will consider how chemical reactions between acids and bases produce chemical balance, and how important it is that we maintain balance in our nutrition.

COMPARE–CONTRAST–CONNECT

Compare the images in Figure 6.1 (a) and (b). What connects them? What makes them different? How might they be related to the inquiry questions for this chapter?

What is the difference between an acid and a base?

Although no longer recommended, historically, the way to determine whether a substance was an **acid** was by tasting it; acidic substances are characterized by their sourness. Lemons, sour milk and vinegar are all examples of substances that taste sour because of the presence of acids.

So what is it that causes the sour taste? Around 1800, Alessandro Volta (after whom volts were named; see Chapter 8) rounded up a group of volunteers, stood them in a line and got them each to pinch the tongue of the person next to them. The two people at the end of the line then put their fingers on battery leads. Immediately, each person in the line described the taste of the person's fingers as sour. Through his experiment, Volta demonstrated that 'sour' is actually caused by the influx of hydrogen ions onto our taste buds. The more hydrogen ions present, the more sour the substance tastes.

EXTENSION: GOING FURTHER

Search for **how taste works** to find out more about the science behind taste. If you are interested in the relationship between different elements, compounds and tastes, do some research to answer the following questions:

- Which elements does the brain perceive as salty?
- Which element tastes like sugar but is actually toxic? What are the effects of ingesting this element?
- What food will you smell of if you touch tellurium or spill it on you?
- What is miraculin and how does it work?
- Which chemicals are able to fool the sense of taste and which receptors do they trick to do it?

ACTIVITY: What do you already know? The acid test ...

ATL

- Communication skills: Negotiate ideas and knowledge with peers and teachers; Organize and depict information logically
- Creative-thinking skills: Use brainstorming and visual diagrams to generate new ideas and inquiries; Make unexpected or unusual connections between objects and/or ideas

In this activity you will be working in pairs to brainstorm information about the topic of acids and alkalis and then collaboratively to **organize** your findings in a mindmap.

Start by brainstorming everything you know about acids and alkalis with your learning partner (see Chapter 5 for more about brainstorming).

Once you are happy with your findings, join another pair to form a group of four, taking your notes with you. Use a large piece of poster paper and write the topic 'Acids and alkalis' in the centre. Mindmap the ideas from your brainstorming session on your poster.

Some categories that you can use to help you start to **classify** and **organize** your information are:

common acids and alkalis

uses

effects

identification methods

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

In *MYP Sciences by Concept 2:* Chapter 2, you were introduced to the definition of an acid as a compound that produces hydrogen ions in solution. Svante Arrhenius (1859–1927), a Swedish chemist, was the first scientist to define acids and **bases** in terms of the ions that they form when they are dissolved in water (in solution). Arrhenius stated that an acid is a substance that produces hydrogen ions (H^+) when dissolved in water:

$$HCl\ (aq) \rightarrow H^+\ (aq) + Cl^-\ (aq)$$

A base is a substance that produces hydroxide ions (OH^-) when dissolved in water:

$$NaOH\ (aq) \rightarrow Na^+\ (aq) + OH^-\ (aq)$$

Hint

The (aq) state symbol next to the NaOH shows that it is a solution.

The splitting of a substance into ions is called **dissociation**.

In the twentieth century, the definitions of an acid and a base were changed. Arrhenius's definition was limiting: there were substances that were regarded as bases but that did not contain hydroxide ions in their formula, for example, ammonia, metallic oxides and hydrogencarbonates. Further, the definition seemed to suggest that acid–base reactions could not take place without water, but we saw in Chapter 4 that the vapour of concentrated hydrogen chloride gas and the vapour of concentrated ammonia gas react to form a visible white smoke of ammonium chloride.

Johannes Brønsted (1879–1947) and Thomas Lowry (1874–1936) are credited with the extension of Arrhenius's definition of acids and bases. A **Brønsted–Lowry acid** was defined as a proton (hydrogen ion) donor and a **Brønsted–Lowry base** was defined as a proton (hydrogen ion) acceptor. You can't have one without the other; they behave as a pair.

Looking at the reaction of hydrogen chloride and ammonia, we can see that the HCl loses its proton (an H^+) and, therefore, behaves as a Brønsted–Lowry acid, and the NH_3 gains the proton and, therefore, behaves as a Brønsted–Lowry base. The product, ammonium chloride, is an ionic solid made up of the ammonium cation (NH_4^+) and the chloride anion (Cl^-).

Figure 6.2 When the vapours of concentrated hydrogen chloride and ammonia solutions meet, they react to form a visible white smoke

$$HCl\ (g) + NH_3\ (g) \rightarrow NH_4Cl\ (s)$$

While the Brønsted–Lowry definition of an acid didn't change the labelling of any acids, it did lead to a distinction between the terms 'alkali' and 'base'. An alkali is a base that is soluble in water. In water, an alkali produces hydroxide ions (so an Arrhenius base is actually an alkali). The terms base and alkali are often used interchangeably because most common bases are alkalis.

All alkalis are bases. Sodium hydroxide is an alkali (Arrhenius base) because it dissolves in water and produces hydroxide ions. But it is also a Brønsted–Lowry base as in the reaction of hydrochloric acid and sodium hydroxide, the hydroxide ion gains a proton from the hydrochloric acid. The latter is a Brønsted–Lowry acid as it loses a proton.

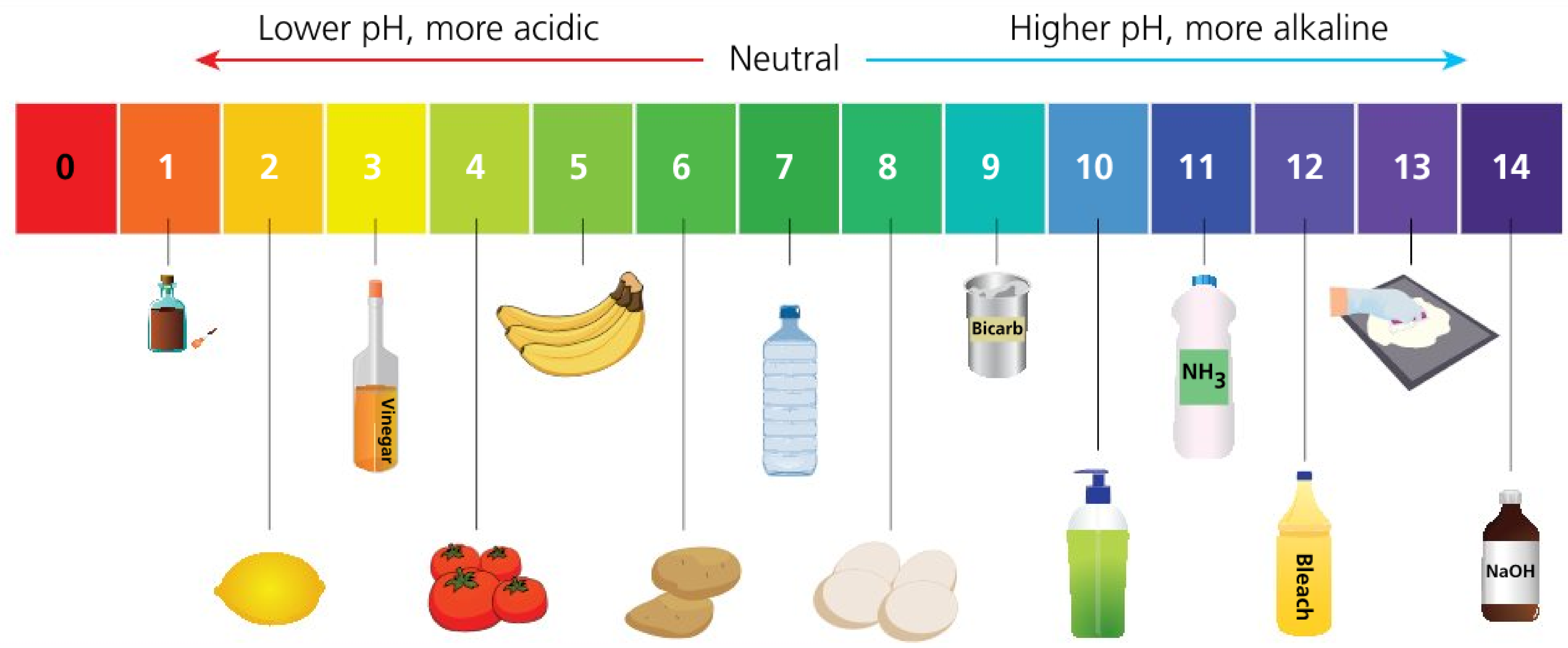
$$HCl\ (aq) + NaOH\ (aq) \rightarrow NaCl\ (aq) + H_2O\ (l)$$

Not all bases are alkalis. Ammonia gas is a base. Ammonia reacts with water to produce a solution of ammonium hydroxide. The ammonium ion is formed by the ammonia gaining a proton, making ammonia a Brønsted–Lowry base, while the hydroxide ion is formed when the water loses a proton (making the water a Brønsted–Lowry acid).

$$NH_3\ (g) + H_2O\ (l) \rightarrow NH_4OH\ (aq)$$

Ammonium hydroxide dissociates into hydroxide ions, so is an alkali.

$$NH_4OH\ (aq) \rightarrow NH_4^+\ (aq) + OH^-\ (aq)$$

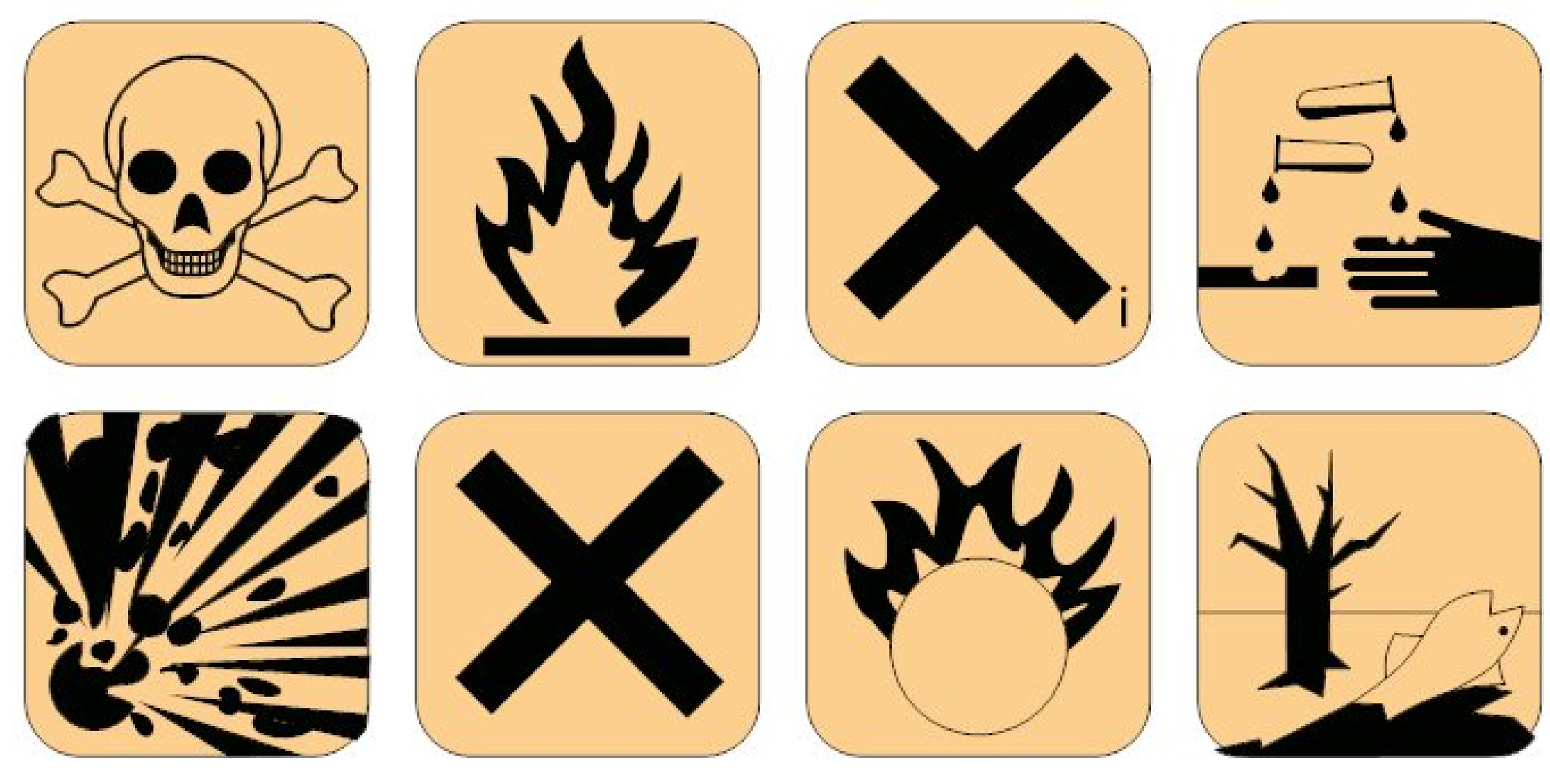


■ **Figure 6.3** The pH scale

THINK–PAIR–SHARE

Individually, study the hazard symbols and decide on a label for each.

With a partner, come up with a meaning for each of the labels. Create a risk assessment (see Chapter 1) for experiments involving acids and bases.



■ **Figure 6.4** Hazard symbols

Name	Use	Formula	Strength	Ions
Acids				
hydrochloric acid	dilute acid in the stomach; often used in products to clean metal surfaces	HCl	strong	H^+ (aq) + Cl^- (aq)
sulfuric acid	car batteries; used to make paints and detergents	H_2SO_4	strong	$2H^+$ (aq) + SO_4^{2-} (aq)
nitric acid	used to make fertilizers, dyes and explosives	HNO_3	strong	H^+ (aq) + NO_3^- (aq)
phosphoric acid	used to make fertilizers, used in anti-rust products and to acidify food and beverages	H_3PO_4	weak	H^+ (aq) + $H_2PO_4^{3-}$ (aq)
methanoic acid (formic acid)	in ant and nettle stings	$HCOOH$	weak	H^+ (aq) + $HCOO^-$ (aq)
ethanoic acid	in vinegar	CH_3COOH	weak	H^+ (aq) + CH_3COO^- (aq)
carbonic acid	in fizzy drinks and sparkling water	H_2CO_3	weak	H^+ (aq) + HCO_3^- (aq)
lactic acid	in sour milk, product of anaerobic respiration	$C_3H_6O_3$	weak	H^+ (aq) + $C_3H_5O_3^-$ (aq)
citric acid	citrus fruits like lemons and oranges	$C_6H_8O_7$	weak	H^+ (aq) + $C_6H_7O_7^-$ (aq)
Bases				
sodium hydroxide	also known as caustic soda; used in drain and oven cleaner (removes grease); used to make soaps and paper	$NaOH$	strong	Na^+ (aq) + OH^- (aq)
potassium hydroxide	similar uses to NaOH; to make soft soaps	KOH	strong	K^+ (aq) + OH^- (aq)
calcium hydroxide	a substance used in water and sewage treatment	$Ca(OH)_2$	strong	Ca^{2+} (aq) + $2OH^-$ (aq)
ammonia	in solution it is used in many cleaning products; used to make fertilizers	NH_3	weak	NH_4^+ (aq) + OH^- (aq)
sodium hydrogencarbonate	in many cooking products, commonly known as baking soda	$NaHCO_3$	weak	H_2CO_3 (aq) + OH^- (aq)

■ **Table 6.1** Common acids and bases: their uses, formulae and the ions they form in water

ACTIVITY: What colour?

ATL

- Communication skills: Organize and depict information logically
- Critical-thinking skills: Practise observing carefully in order to recognize problems; Gather and organize relevant information to formulate an argument; Draw reasonable conclusions and generalizations

Equipment and materials (per group)

- Spotting tile
- Hydrochloric acid solution, 0.1 M
- Lemon juice
- Sodium hydroxide solution, 0.1 M
- Bicarbonate of soda solution, 0.1 M
- Litmus paper, blue and red
- Phenolphthalein
- Methyl orange
- Universal indicator solution
- Plastic pipettes

Safety: Wear safety goggles throughout. At these concentrations, the hydrochloric acid is not regarded as hazardous, while sodium hydroxide is classified as an irritant. The indicators should be less than 1 per cent of the dye though the solvent and/or other reagents may be flammable or present additional hazards.

Method

1. **Draw** a table to record the colours shown by an acid and an alkali in different indicators. Your table should also include the initial colour of the indicator. This is also the colour that would appear when a neutral substance is tested.
2. Add 2–3 drops of the substance you are testing to one of the spots in the spotting tile.
3. Add 2–3 drops of the indicator you are testing to the same spot. If you are using litmus paper, you only need a piece about 1 cm long; place it so that the edge is hanging out over the side and is not completely submerged (this allows you to see the original colour).
4. Record the final colour of the indicator in your table.
5. Repeat the process in a systematic way, so that you test all four of your substances with all five of the indicators. When your spotting tile is full, rinse it clean with water; the waste can go down the sink.
6. When your table is complete, clean your spotting tile and place 2–3 drops (or a small 1 cm strip) of each indicator in a different spot (you should have used five spots in total). Label the tile with the name of each indicator.
7. Add five drops of the hydrochloric acid solution to each indicator. Take a picture of the spotting tile.
8. Add one drop of the sodium hydroxide solution to each indicator. Take a picture of the spotting tile.
9. Continue to add one drop of sodium hydroxide solution at a time to each indicator, taking a picture after each drop. Take your last picture when 10 drops have been added.

Analysis

1. **Research** what an acid–base indicator is and find out which specific ions are responsible for the colour changes. Write a short summary about how they work.
2. **Describe** the general trend in colour changes of acids and bases that are shown in your results table.
3. Use the pictures you took in the second part of the experiment to **describe** the results and **suggest** what was happening each time a drop was added.
4. Use both parts of the experiment to **evaluate** the different indicators used. What are the advantages and disadvantages of each?

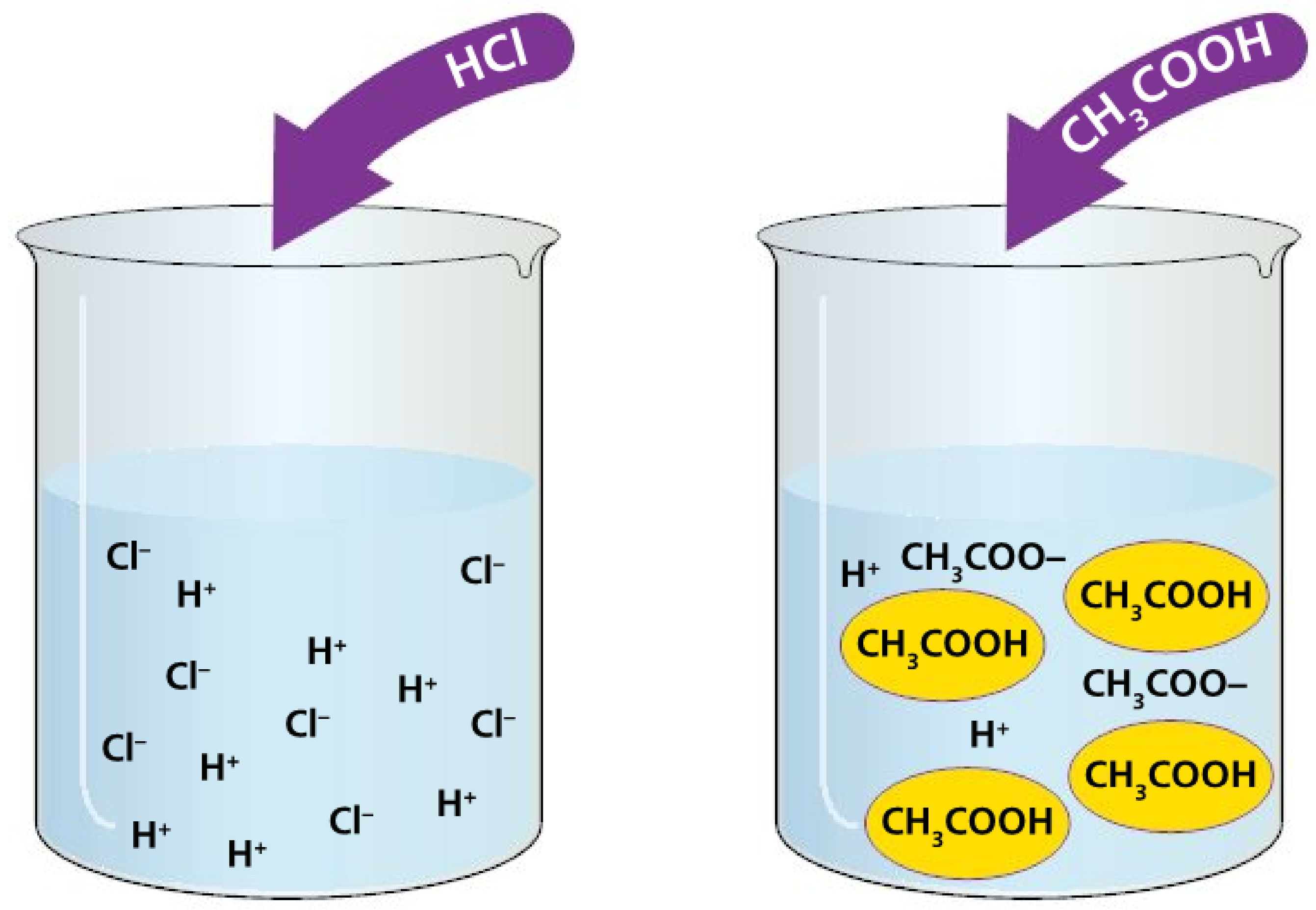
Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

The activity *What colour?* demonstrated that acids and bases can have different strengths. The only indicator capable of differentiating between the strengths of acids and bases is universal indicator, which is a mixture of dyes that is able to produce a different colour depending on the strength of the acid or base. The strength is indicated by the pH value.

The pH scale, which is linked to specific colours that universal indicator can change to, indicates the strength of an acid or a base. The pH scale has no units. Figure 6.3 shows the pH of some common household items.

The strength of an acid depends on how good a proton donor it is; in other words, how many H^+ ions will be produced from a given number of acid molecules. So an acid that fully dissociates is a **strong acid**, while an acid that only partially dissociates is a **weak acid**. Most acids, especially those we meet in organic molecules, are weak acids. Table 6.1 identifies some common acids.



■ **Figure 6.5** Strong and weak acids. Hydrochloric acid, a strong acid, fully dissociates to H^+ ions; ethanoic acid, a weak acid, only partially dissociate to H^+ ions.

The dissociation of strong acids is shown with a forward-facing arrow, indicating that the substance completely splits into ions; the dissociation of a weak acid is often indicated with a reversible sign, showing that only some of the substance dissociates, while most remains as molecules (reversible reactions are considered in more detail in Chapter 11).

$HCl\ (aq) \rightarrow H^+\ (aq) + Cl^-\ (aq)$

$CH_3COOH\ (aq) \leftrightharpoons CH_3COO^-\ (aq) + H^+\ (aq)$

The same philosophy is applied to strong and weak bases. Sodium hydroxide fully dissociates in water so is a strong base. Ammonia reacts with water to produce ammonium hydroxide; this is a weak base as it only partly dissociates.

$NaOH\ (aq) \rightarrow Na^+\ (aq) + OH^-\ (aq)$

$NH_4OH\ (aq) \leftrightharpoons NH_4^+\ (aq) + OH^-\ (aq)$

So what does pH measure? pH is a measure of the concentration of hydrogen ions (the number of ions in a given amount of solution). A large concentration of hydrogen ions will make the substance acidic. If the number of hydrogen ions (H^+) is equal to the number of hydroxide ions (OH^-), then the substance will be neutral. Water, for example, very slightly dissociates into H^+ and OH^- ions. There are very few ions present, but there is an equal number of each type. An alkaline substance has a high concentration of hydroxide ions, therefore, a small concentration of hydrogen ions.

So why do strong acids have the lowest pH? This is because the pH scale is a negative one, which means a lower pH is a more acidic substance. Further, it is a logarithmic one, which means that as you move down the pH scale by a pH of 1, you are actually increasing the number of hydrogen ions, and thus the acidity, by a factor of 10. So hydrochloric acid, which has a pH of 1, is one million times more acidic (has one million more hydrogen ions) than neutral water, which has a pH of 7.

The terms 'strong' and 'weak' are often confused with the terms 'concentrated' and 'dilute'. While strong and weak refer to the tendency to form ions in solution, the term **concentration** refers to how much of the substance there is in a given volume of solution. Adding one drop of sulfuric acid to a huge tank of water produces a very dilute solution of sulfuric acid, but sulfuric acid remains a strong acid because all of the molecules in that one drop would dissociate. In the same way, if you had a concentrated solution of a weak acid, even though there would be many acid molecules present, it would still be a weak acid as only a few would dissociate into ions. A strong and a weak acid can be distinguished by measuring the pH of the same *concentration* of each substance.

Logarithmic scales

Logarithmic scales are often used in sciences to represent variables whose values change over very large ranges, as a power index. In the case of pH, we have seen that the pH represents the increase in acidity (number of hydrogen ions) in powers of 10; so

pH 1 to pH 2 represents an increase of 10 times, $\times10^{(2-1)} = \times10^1$

pH 1 to pH 3 represents an increase of 100 times, $\times10^{(3-1)} = \times10^2$

and so on.

Another example of a base 10 logarithmic scale is the decibel scale for sound (see *MYP Physics by Concept 4&5:* Chapter 7).

Creating solutions of varying concentrations by dilution

Sometimes experiments require solutions of different concentrations. This can be done by diluting a known concentration of the solution (usually with distilled water) but keeping the same **total volume** of solution each time. Table 6.2 shows an example of how to obtain different concentrations of 100 cm^3 of hydrochloric acid (HCl).

Original concentration of HCl solution/mol dm^{-3}	Volume of HCl solution/cm^3	Volume of distilled water/cm^3	Total volume/cm^3	Final concentration of HCl solution/mol dm^{-3}
1.00	100	0	100	1.00
1.00	75	25	100	0.75
1.00	50	50	100	0.50
1.00	25	75	100	0.25
1.00	10	90	100	0.10
1.00	1	99	100	0.01

■ **Table 6.2** Obtaining multiple concentrations of hydrochloric acid solution by dilution

Serial dilution can be used to prepare solutions that are diluted by the same factor each time.

ACTIVITY: Make it sour!

ATL

- Communication skills: Write for different purposes; Paraphrase accurately and concisely
- Information literacy skills: Collect and analyse data to identify solutions and make informed decisions; Evaluate and select information sources and digital tools based on their appropriateness to specific tasks; Create references and citations, use footnotes/endnotes and construct a bibliography according to recognized conventions

■ **Figure 6.6** Sour-tasting sweets

Do you love sour-tasting sweets? Have your parents ever pulled a face after stealing one, asking you how you can eat something so sour? There is evidence that children like sour tastes much more than adults. Food scientists help companies design foods that take the preferences of consumers into account.

You are going to write an article for your school newspaper about the types of acids that are used in sweets and evaluating the impacts of these.

Your article must include:

- **A brief summary of what the problem is and how science has solved it (make reference to the properties of the specific acids that are added to sweets, searching for acids added to sweets to make them sour).**
  - **It might also be useful to include some scientific background on acids and pH.**
- **A discussion of the benefits and limitations of creating sour sweets linking this to a relevant world factor (social, economic, political,cultural or ethical).**
- **An overall conclusion about whether sweets should be sour.**
- **Include scientific terminology, remembering to explain any terms that younger students reading the article might struggle to understand.**
- **Document your sources in a bibliography. Include citations for any images included in your article.**

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

How do acids react?

In this section we will be looking at some of the most common reactions of acids. We will start with one of the most important ones, **neutralization**. The most common neutralization reaction is the reaction between an acid and an alkali. What you may not have realized, however, is that no matter what acid or alkali are reacting together, the same chemical reaction happens each time. This is something that only becomes clear when we look at the ionic equations of the reactions.

An ionic equation is one that removes any 'spectators' and includes only the species that are actually taking part in the reaction. The following steps will help you derive an ionic equation from any balanced symbol equation; the steps are supported with the example of the reaction of hydrochloric acid with sodium hydroxide.

1. Write a balanced symbol equation for the reaction including any state symbols (refer to Chapter 4 for help with this if necessary).

   $HCl\ (aq) + NaOH\ (aq) \rightarrow NaCl\ (aq) + H_2O\ (l)$

2. Split any substance that is in solution into its component ions.

   $H^+\ (aq) + Cl^-\ (aq) + Na^+\ (aq) + OH^-\ (aq) \rightarrow Na^+\ (aq) + Cl^-\ (aq) + H_2O\ (l)$

Hint

If any of the ions or polyatomic ions have a subscript, this is converted to a coefficient. For example, H_2SO_4 (aq) would become $2H^+$ (aq) + SO_4^{2-} (aq).

3. Cancel out any substances that appear on both the reactant and product sides of a reaction. The ionic equation is what is left.

   $H^+\ (aq) + \cancel{Cl^-\ (aq)} + \cancel{Na^+\ (aq)} + OH^-\ (aq) \rightarrow \cancel{Na^+\ (aq)} + \cancel{Cl^-\ (aq)} + H_2O\ (l)$

   $H^+\ (aq) + OH^-\ (aq) \rightarrow H_2O\ (l)$

What becomes clear from the ionic equation is that the hydrogen and hydroxide ions react together to form neutral water. This is why a substance is neutral (pH 7) when there is an equal number of hydrogen and hydroxide ions, as they are able to react together and be removed from the solution. The other product, a salt, remains in solution. Therefore, the definition of a neutralization reaction can be refined so that it is a reaction between an acid and a base, to produce a salt and water, whereby there are no excess H^+ or OH^- ions left.

I USED TO THINK … NOW I THINK …

Using the steps outlined, write ionic equations for the following reactions:

- **the reaction of nitric acid with potassium hydroxide**
- **the reaction of sulfuric acid with lithium hydroxide.**

How has your understanding of a neutralization reaction of an acid and an alkali changed? Reflect on this by answering the following questions:

I used to think …

Now I think ...

A neutralization reaction is a chemical reaction between an acid and a base. As we have seen previously, an alkali is a soluble base. Other bases that will neutralize acids include metal oxides, insoluble metal hydroxides, metal carbonates and metal hydrogencarbonates. The reaction of an acid and a base will always produce a salt and water. The general equations for these reactions are:

acid + alkali/insoluble metal hydroxide/metal oxide → salt + water

acid + metal carbonate/hydrogencarbonate → salt + water + carbon dioxide
(Note that carbon dioxide is additionally produced in this reaction)

Acids also react with metals to produce a salt and hydrogen gas.

acid + metal → salt + hydrogen

If you haven't carried out experiments of acids with metals or metal carbonates, see *MYP Sciences by Concept 2:* Chapter 2, activities *Acidic spices* and *Dissolving buildings*.

In Table 6.1, you met the names and formulae of some common acids. You may have noticed that the name of the salt produced in a neutralization reaction or in a reaction of an acid with a metal is closely linked to the name of the acid used in the reaction. Salts are formed by replacing the hydrogen ions in the acid with another positive ion, usually a metal ion. If you cast your mind back to Chapter 4 where we discussed the names of polyatomic ions, you will see a link between the name of the polyatomic ion, the acid it comes from and the salt it produces. The metal component of the salt comes from the base or metal.

Name of acid	Formula of acid	Formula of anion component of salt (polyatomic ion)	Name of ending of salt (polyatomic ion)
hydrochloric acid	HCl	Cl^-	chloride
sulfuric acid	H_2SO_4	SO_4^{2-}	sulfate
sulfurous acid	H_2SO_3	SO_3^{2-}	sulfite
nitric acid	HNO_3	NO_3^-	nitrate
nitrous acid	HNO_2	NO_2^-	nitrite
phosphoric acid	H_3PO_4	PO_4^{3-}	phosphate
ethanoic acid	CH_3COOH	CH_3COO^-	ethanoate

■ **Table 6.3** Acids and their salts

Neutralization reactions are a big part of our everyday lives. We rely on them for health and hygiene and even for cooking, and it all comes down to the chemistry of the substances contained within the products. Watch this video to find out about one specific healthcare product: **https://youtu.be/ClwiGwg0M7g**

EXTENSION: GOING FURTHER

Do some research into the acid–base nature of the period 3 oxides. What are the formulae of each of the oxides? What are amphoteric oxides? What is the difference between amphoteric and amphiprotic?

Hint

Acids that end in '-ic' make salts that end in '-ate' (except hydrochloric acid).

Acids that end in '-ous' make salts that end in '-ite'.

THINK–PAIR–SHARE

Individually, **think** of any examples from your everyday life that involve a neutralization reaction. Consider any animals or plants that use acids as a form of defence.

Share your ideas with a learning partner. Come up with a list of examples, separating them into ones that you are certain about and ones that you are unsure about.

Present your findings as a class, discussing any of the 'unsure' examples. Compile a class list of examples of neutralization reactions from your everyday lives.

ACTIVITY: Neutralize it Agony Aunt!

ATL

- Transfer skills: Apply skills and knowledge in unfamiliar situations; Inquire in different contexts to gain a different perspective; Combine knowledge, understanding and skills to create products or solutions

You have a part-time job working as the Agony Aunt for a science magazine and have received many questions about everyday problems linked to acids and bases. In this activity, you will work together as a class to create a collection of responses in the form of letters to the questions you have been asked. Each member of the class should choose one problem to focus on, find out about it and then identify the solution.

Your letter should include the following:

- **a recap of what the problem is**
- **an idea of how the problem can be solved; household remedies should be suggested if possible; you should ensure you include a scientific explanation of the solution**
- **any side-effects or other issues that might arise as a result.**

Remember to write your response in the form of a letter.

The problems:

- **The bottom of my kettle is covered in a white substance. Is it dangerous? How can I get rid of it?**
- **My oven is full of grease and every time I turn it on, it produces a horrible smell. How can I clean it?**
- **There are bees and wasps in my garden. I am really worried about getting stung. What should I do if I am?**
- **I love to go walking outdoors with my young children but I am really worried about them getting stung by nettles. Why are nettle stings so painful and are they dangerous?**
- **I don't understand why my hydrangea bushes sometimes produce pink flowers and sometimes produce blue flowers. Why does this happen and what can I do to produce only blue flowers?**

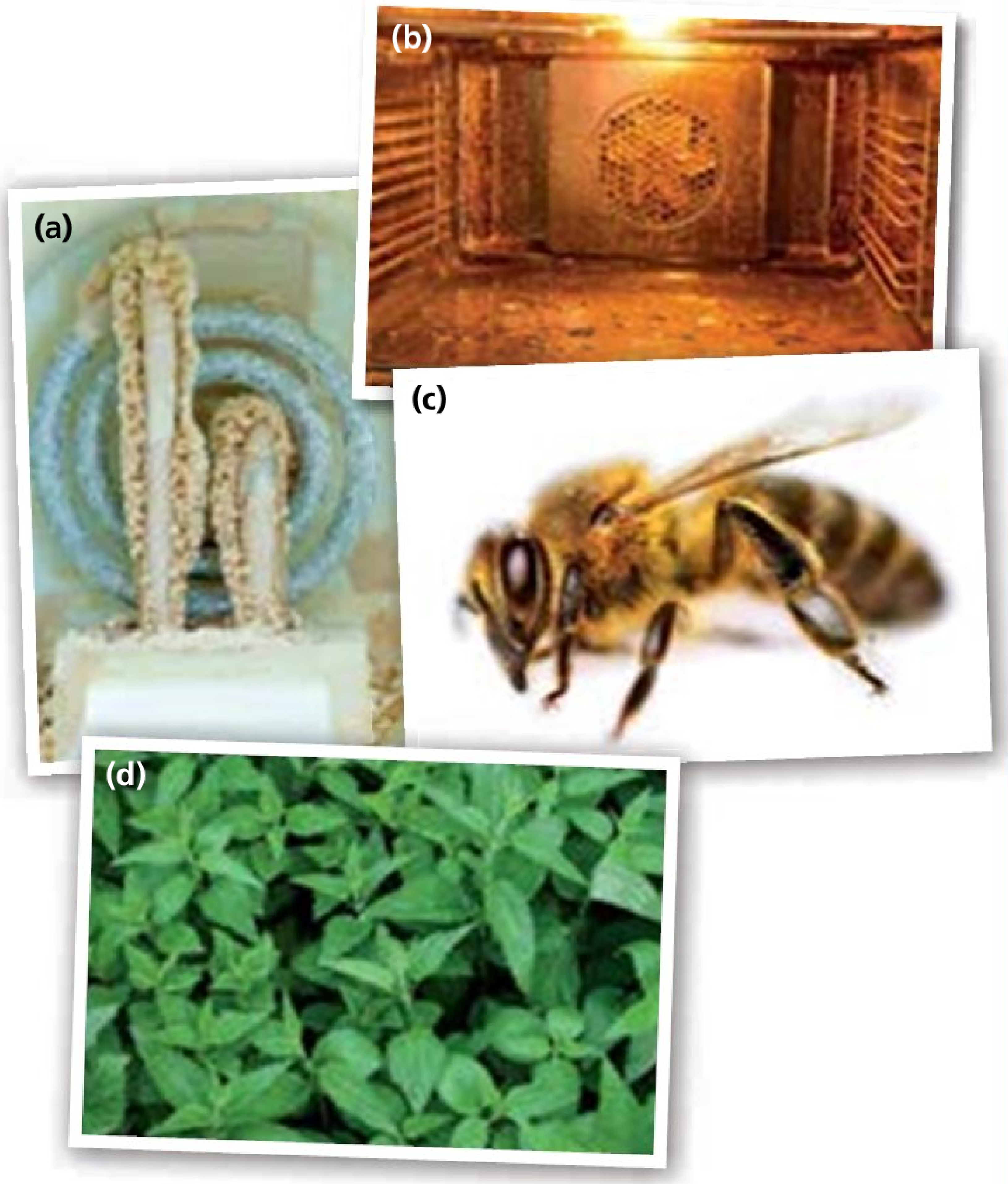


Figure 6.7 (a) What's in my kettle?; (b) clean that oven ...; (c) getting stung; (d) watch out for the nettles!

When you have completed your letters, **present** them to the rest of the class, so that you have the opportunity to find out about other problems that can be solved using your knowledge of acids and bases.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion D: Reflecting on the impacts of science.

How do we make salts?

A salt is an ionic compound that is produced from the reaction of an acid and a base by replacing the hydrogen ion in the acid with a metal ion. Depending on what your starting materials are, the salt produced can be **soluble** or **insoluble**. Table 6.4 has a set of rules that will help you determine whether a salt formed in a chemical reaction is soluble or not.

Depending on the physical state of your starting materials, there are different methods to make soluble salts.

Ion	Solubility
Na^+, K^+, NH_4^+	all salts are soluble
halides (Cl^-, Br^-, I^-)	all soluble except silver (Ag^+) and lead (Pb^{2+})
nitrate (NO_3^-)	all salts are soluble
sulfates (SO_4^{2-})	all salts are soluble except calcium (Ca^{2+}), barium (Ba^{2+}), lead (Pb^{2+}) and silver (Ag^+)
carbonates (CO_3^{2-})	all salts are insoluble except sodium (Na^+), potassium (K^+), ammonium (NH_4^+)
phosphates (PO_4^{3-})	all salts are insoluble except sodium (Na^+), potassium (K^+), ammonium (NH_4^+)

Table 6.4 Solubility rules for salts

ACTIVITY: Making a soluble salt

ATL

- Information literacy skills: Make connections between various sources of information; Collect and analyse data to identify solutions and make informed decisions; Process data and report results

We will be using the excess solid method which can be used if you are reacting an insoluble metal oxide or carbonate.

Materials

- **Copper (II) oxide powder**
- **Sulfuric acid, 0.1 M**
- **A 25 cm³ measuring cylinder**
- **Beaker**
- **Spatula**
- **Stirring rod**
- **Bunsen burner**
- **Heatproof mat**
- **Tripod**
- **Wire gauze**
- **Filter funnel**
- **Filter paper**
- **Conical flask**
- **Evaporating basin**
- **Tongs**

Safety: Safety goggles must be worn at all times. Hair should be tied back and students should carry out the experiment standing up. Students should be careful when dealing with the hot equipment and should practise lifting the beaker and evaporating basin with the tongs before starting the experiment. Take care when handling the copper (II) oxide as the fine powder can cause eye irritations. It can also form an explosive mixture in contact with magnesium or aluminium. At this concentration, sulfuric acid is not classified as hazardous.

Method

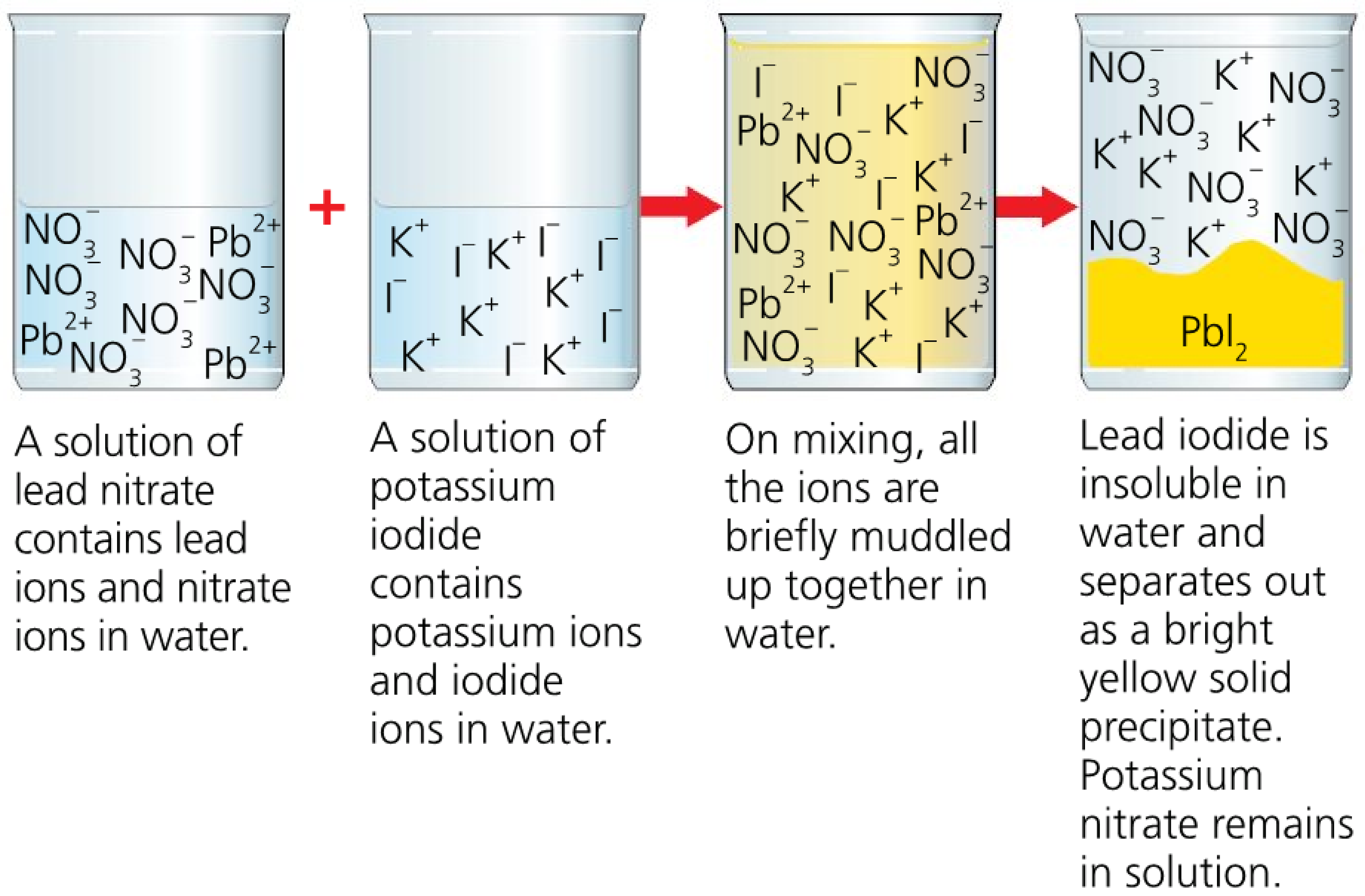
1. **Add approximately 20 cm³ of sulfuric acid to your beaker.**
2. **Warm the acid on the Bunsen burner gently for about 1 minute, before turning it off.**
3. **Add an excess of copper (II) oxide to the sulfuric acid. To add an excess, add 2–3 spatulas of copper (II) oxide and stir with the stirring rod. Keep adding copper (II) oxide until no more dissolves and you see it start to build up at the bottom of the beaker.**
4. **Filter the mixture; any unreacted copper (II) oxide will be collected as residue in the filter paper, while the solution of the soluble salt will pass through into the conical flask as the filtrate.**
5. **Pour the filtrate into an evaporating basin.**
6. **Heat the solution gently for 2–3 minutes. Turn off the heat.**
7. **Allow the solution to cool and crystallize overnight.**

Analysis

1. **Suggest why you heated the sulfuric acid before adding the copper (II) oxide.**
2. **Explain why the copper (II) oxide was added in excess.**
3. **State your observations when you added the copper (II) oxide to the sulfuric acid.**
4. **Formulate a balanced symbol equation with state symbols for the reaction of copper (II) oxide with sulfuric acid.**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.



■ **Figure 6.8** The ions involved in the precipitation reaction of lead nitrate and potassium iodide

Titrations can also be carried out to prepare a soluble salt. The two methods for preparing soluble salts are summarized here: **www.youtube.com/watch?v=lpM_VCMPFug**

Insoluble salts are prepared through a **precipitation reaction**. Two soluble salts are added together in a test tube; the combination of soluble salts is selected specifically so that the ions 'swap partners' (a double displacement reaction) and an insoluble salt is produced. The insoluble salt appears as a precipitate and is then separated by filtration.

Let's look at an example. Lead iodide is an insoluble salt, so the soluble salts that you start with need to contain lead ions and iodide ions. All salts of the halogens and nitrates are soluble, so we can use lead nitrate as one of our starting salts and potassium iodide as the other starting salt. Figure 6.8 shows how the ions of the soluble salts mix and form the precipitate.

So what is the chemical reaction that produces the precipitate? This is best shown by returning to the ionic equation of the reaction.

A balanced symbol equation for the reaction is:

$$Pb(NO_3)_2\ (aq) + 2KI\ (aq) \rightarrow PbI_2\ (s) + 2KNO_3\ (aq)$$

Splitting the aqueous substances into their ions gives:

$$Pb^{2+}\ (aq) + 2NO_3^-\ (aq) + 2K^+\ (aq) + 2I^-\ (aq) \rightarrow PbI_2\ (s) + 2K^+\ (aq) + 2NO_3^-\ (aq)$$

Removing the spectator ions results in:

$$Pb^{2+}\ (aq) + 2I^-\ (aq) \rightarrow PbI_2\ (s)$$

ACTIVITY: Making insoluble salts

ATL

- Communication skills: Use and interpret a range of discipline-specific terms and symbols
- Creative-thinking skills: Make guesses, ask 'what if' questions and generate testable hypotheses; Apply existing knowledge to generate new ideas, products or processes
- Critical-thinking skills: Interpret data; Draw reasonable conclusions and generalizations; Identify obstacles and challenges

1. **Deduce whether the following salts are soluble or insoluble.**
   - **a Calcium nitrate**
   - **b Sodium chloride**
   - **c Silver bromide**
   - **d Ammonium carbonate**
   - **e Barium sulfate**
2. **Suggest combinations of soluble salts that could be used to create the salts you have identified as insoluble in Question 1.**
3. **Formulate balanced symbol equations with state symbols for the salt combinations you suggested in Question 2.**
4. **Formulate ionic equations from the balanced symbol equations in Question 3.**
5. **Carry out some research to identify a factor that could affect the solubility of an ionic compound.**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

How does form meet function in the digestive system?

Humans can eat varied foods due to their developed digestive systems that break down large molecules into smaller ones, able to pass into the **bloodstream** and travel around the body to be used for growth, repair and energy.

WHAT DOES OUR FOOD CONSIST OF?

The small substances that make up our food are called nutrients. These are organized into seven groups as shown in Table 6.5. To be healthy, our diet must be balanced and contain the correct variety and amounts of nutrients from each of these seven groups.

Nutrient group	Use/function in humans	Good food sources	Chemical composition and other details
carbohydrates 	main source of energy	simple sugars: fruits, vegetables, milk complex sugars: pasta, rice, bread, cereals, potatoes, grains	• contain the elements C,H,O • simple sugars (mono- and disaccharides) such as glucose, fructose and galactose • complex sugars (polysaccharides) made up of starch; they last longer in the body
proteins 	for growth and repair of cells; enzymes, hormones and antibodies are all made up of protein and so are hair and nails	animal sources: meat, fish, poultry, eggs, cheese, milk plant sources: legumes such as beans and lentils, soya beans and tofu	• contain the elements C, H, O, N • made up of 20 amino acids; nine of them are called **essential amino acids** and plant sources may lack some of them • the rest are called non-essential amino acids and can be synthesized in the body
fats (lipids) 	source and storage of energy in the body; insulate the body and vital organs and structures; cell membranes and some hormones are made of fats	animal sources: butter, milk, cheese, meat, eggs plant sources: oils and oil-rich seeds	• contain the elements C, H, O • made up of fatty acids and glycerol • saturated fats mainly in animal sources • unsaturated fats mainly in plant sources • unsaturated fats are split into **monounsaturated fats** and **polyunsaturated fats**
vitamins 	needed in small amounts but are essential for the correct functioning of the cells; lack of vitamins causes **vitamin deficiency**	mainly: fruits, vegetables, cereals, dairy, eggs, meat, fish, oils, nuts	• simple molecules that contain the elements C, H, O and sometimes S, N, Co • there are 13 vitamins • water-soluble: vitamin C, B vitamins • fat-soluble: vitamins A, D, E, K
minerals 	needed in small amounts but are essential; a lack of minerals causes mineral **deficiency** e.g. a lack of iron causes **anemia**	mainly: fruits, vegetables, dairy, meat, nuts, legumes, seafood	chemical elements such as: Ca, P, K, Na, Mg, Fe, Zn, I, Cl, Cu; they are needed in small amounts
fibre 	gives a bulky consistency to food to help it move through the digestive system; slows down the absorption of some molecules such as sugars; a lack of fibre causes constipation	soluble fibre: oats, rye, carrots, potatoes, bananas and apples; insoluble fibre: wholemeal bread, cereals, wholegrain rice, nuts and seeds	• contains the elements C, H, O • soluble fibre: dissolves in water and makes a gel; fermented by bacteria in the large intestine • insoluble fibre: absorbs water and becomes bulky but does not dissolve in water
water 	we are made up of approximately 80 per cent water; water is the medium in which all biochemical processes in the body take place	the best source of water is actually water; fruits, vegetables and milk contain water	water (H_2O) is a compound made up of the elements H and O

■ **Table 6.5** Summary of the seven groups of nutrients needed for a balanced diet

DISCUSS

In Figures 6.9 and 6.10 the main organs and steps of the digestion process are summarized. Which organs are involved in each step of the process?

Discuss your answers with your partner and then copy and complete Figure 6.10.

HOW DO WE DIGEST THE FOOD WE EAT?

Until 1833, it was believed that digestion was only a mechanical process involving mixing, mashing and squeezing. It was not until the experiments conducted by Dr William Beaumont on his patient Alexis St Martin that it was discovered that digestion in the stomach actually involved a chemical process facilitated by acid. In June 1822, St Martin was accidentally shot in the stomach and miraculously survived his injuries. He was treated by an army surgeon, Dr Beaumont. St Martin's injury never fully healed and he was left with a 'hole' through his abdomen which acted like a small window to his stomach! Dr Beaumont began experimenting on him by tying a piece of food to a string and inserting it into his stomach through the hole. He would remove the food sample every few hours and make observations about the changes that occurred. He also took a sample of the **gastric juice** to analyse it and used it to digest pieces of food in cups, proving that digestion is, in fact, a chemical as well as a mechanical process. It is now understood that inside the digestive system, the two types of digestion, **mechanical** and **chemical**, occur almost simultaneously.

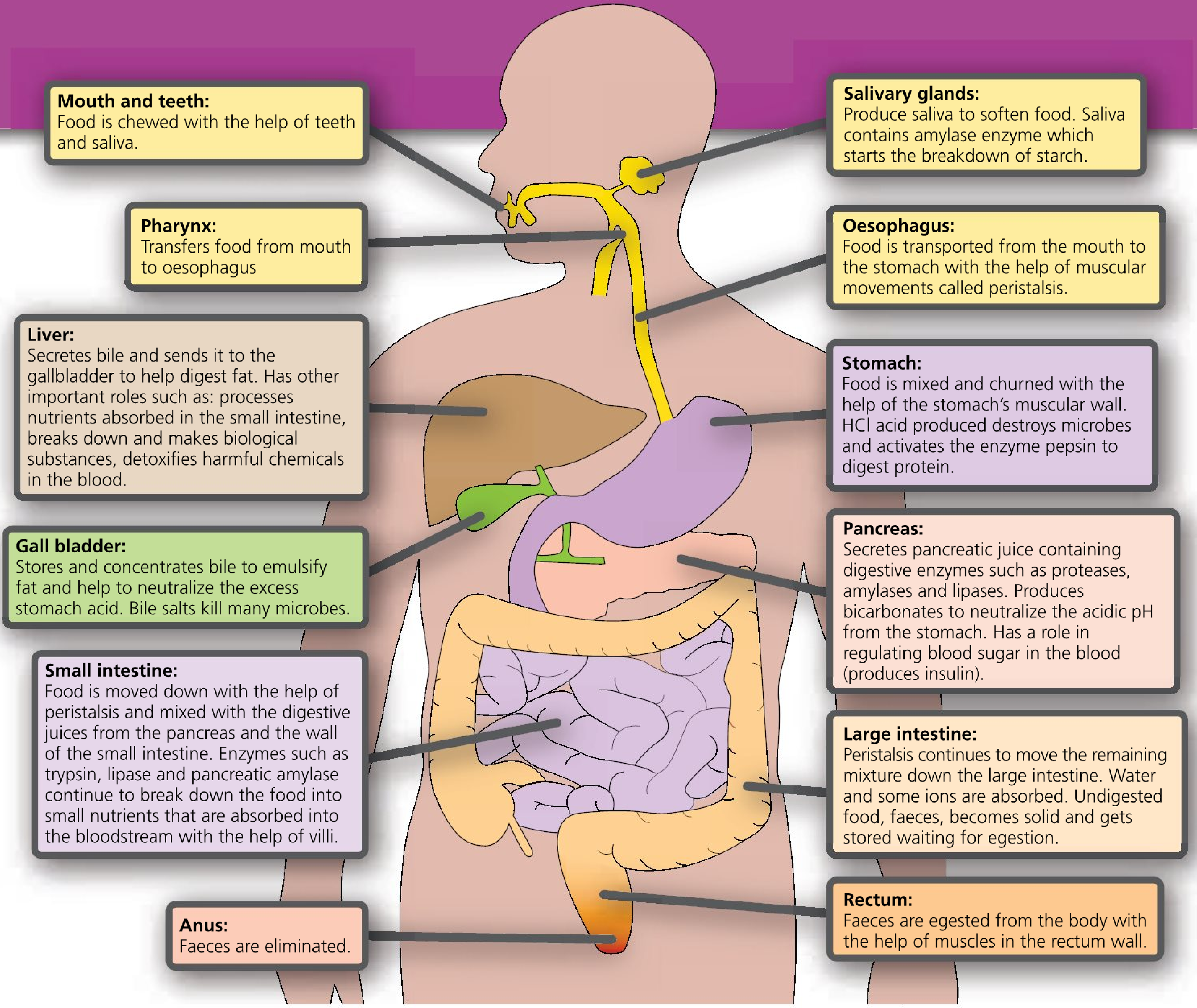
THE DIGESTION PROCESS

Figure 6.9 summarizes the process of digestion. The digestive system in humans consists of the **alimentary canal** and associated organs. **Ingested** food passes through the digestive system slowly and, as it passes, a series of chemical and physical changes happen to it. Chemical changes involve the action of digestive enzymes and other substances, such as hydrochloric acid (HCl) and bicarbonate. Physical changes involve the mechanical action of the teeth and saliva, the three-layered muscular stomach wall that mixes the stomach contents, **peristalsis** along the alimentary canal and even bile, which helps to expose fat droplets to the enzyme lipase. All these changes transform large molecules of food and break them down into nutrients small enough to be **absorbed** through the wall of the small intestine to reach the blood. The structure of the small intestine is adapted to maximize and facilitate absorption. In the large intestine, water gets removed from undigested substances such as fibre (humans, unlike some animals, do not possess enzymes to break down fibre) and other waste products forming **faeces**. Faeces are temporarily stored in the rectum until they are egested in the process of **defecation**.

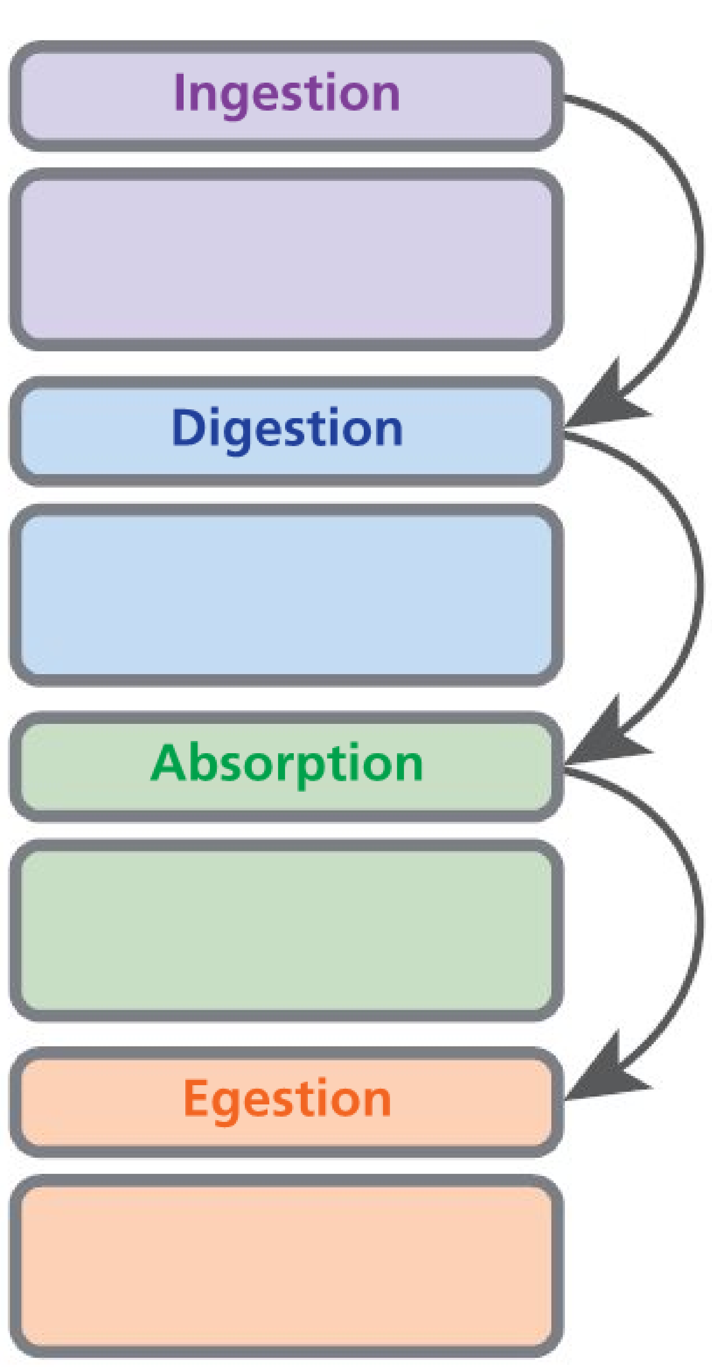
The process of digestion can be summarized in four steps as shown in Figure 6.10.

Name of enzyme	Where it is produced in the body	Where it does its job	Food it breaks down	Nutrients produced	Optimum pH for the enzyme
salivary amylase	salivary glands	mouth	starch	maltose	7
pepsin	stomach wall	stomach	protein	polypeptides	2
pancreatic amylase	pancreas	small intestine	starch	maltose	7
trypsin	pancreas	small intestine	protein	polypeptides	7
lipase	pancreas	small intestine	fat (lipids)	fatty acids + glycerol	7
maltase	wall of small intestine	small intestine	maltose	glucose	7
peptidase	wall of small intestine	small intestine	polypeptides	amino acids	7
sucrase	wall of small intestine	small intestine	sucrose	glucose + fructose	7

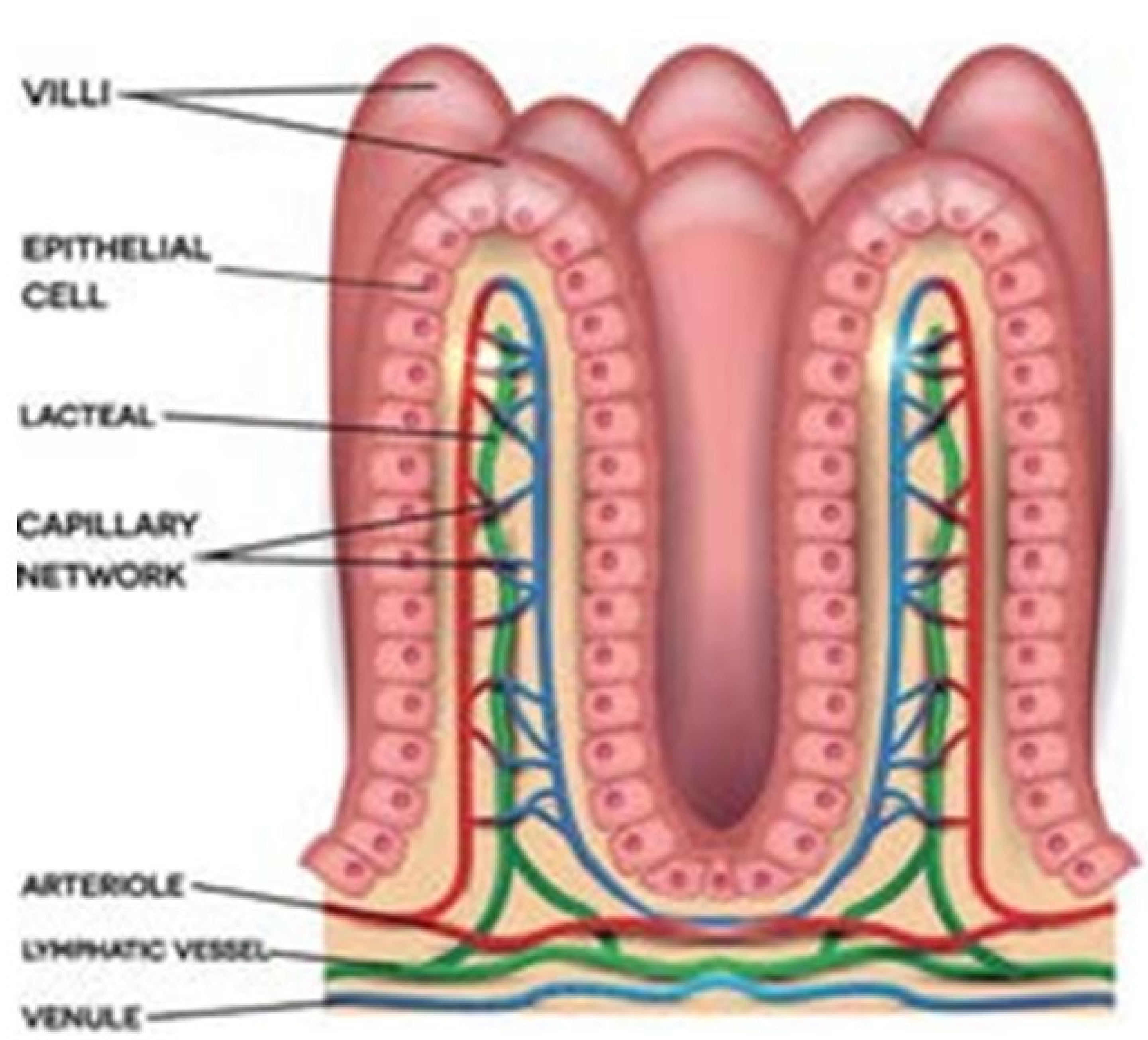
■ **Table 6.6** Summary of the main enzymes found in the digestive system



■ **Figure 6.9** Structure and main functions of the human digestive system



■ **Figure 6.10** The four steps of the digestion process



■ **Figure 6.11** Structure of villi in the human intestine

ACTIVITY: Is it chemical or mechanical?

ATL

- Critical-thinking skills: Gather and organize relevant information
- Collaboration skills: Build consensus

In this activity you will use information presented to you in a diagram and a table and **interpret** it to make judgments about how to **organize** and **summarize** it in a different form.

1. **In pairs, analyse the information presented in Figure 6.9 and Table 6.6 then determine which organs of the digestive system form part of the alimentary canal.**
2. **Make a copy of Table 6.7 and then list the organs that you identified in the first column of your table. (Information about the mouth has already been completed to help you.)**
3. **Summarize the functions of these organs in the second column of the table.**
4. **In the third column, state which type(s) of digestion (chemical or mechanical) takes place in the structure you are studying. Make sure that you justify your answer by specifying which information helped you to make your judgment.**
5. **In the fourth column, state which type of food is digested then state which nutrient results from this digestion in the fifth column.**
6. **Using three different colouring pencils or highlighters, highlight which process happens in an *acidic*, *alkaline* or *neutral* environment.**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

Structure/organ in the digestive alimentary canal	Summary of what happens in this structure	Type of digestion (mechanical vs chemical); name the enzymes when appropriate	Type of food digested	Nutrients produced
mouth	food is chewed with the help of teeth saliva softens food salivary amylase starts to digest starch	chemical: action of amylase mechanical: action of teeth (mash food) and saliva (soften food) and tongue (move food around)	starch	maltose

■ **Table 6.7**

ABSORPTION

The process by which digested food substances are taken into the blood is called **absorption**. Although some absorption happens at different locations in the digestive system, such as the absorption of water and medication like aspirin in the stomach, the small intestine is the main site of absorption in the body. This is due to the presence of special structures that line the entire length of the small intestine called villi (plural of villus). In turn, each villus has small projections called microvilli. Villi and microvilli increase the surface area and only allow small molecules to reach the blood thanks to their **semi-permeable** membrane.

EXTENSION

Inside each villus there is a **lacteal**. What is its role and which nutrients does it help to absorb? Use your browser or visit your school library to find out.

Links to: Mathematics

Geometry

Shapes are an important aspect of science and nature. Any scientist should be able to make the connection and use basic mathematical formulae and concepts in order to calculate surface areas and volumes of 3D objects or living things.

ACTIVITY: How much bigger?

ATL

- Critical-thinking skills: Use models and simulations to explore complex systems and issues
- Transfer skills: Apply skills and knowledge in unfamiliar situations
- Communication skills: Understand and use mathematical notation

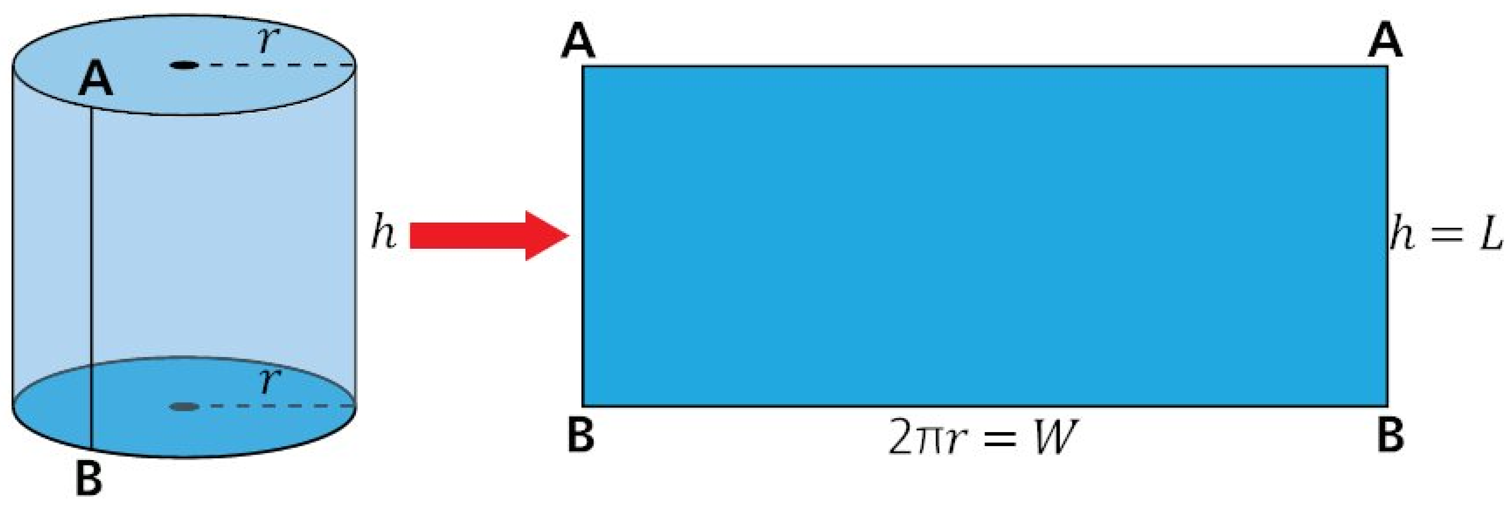
Background

The small intestine is a tube with a length that varies between individuals and ranges from 2.5 m to 10 m. Its diameter ranges from 2.5 cm to 3 cm in adult humans. We have learnt that the small intestine is lined with villi and, in fact, each square centimetre of intestine contains 1000–4000 villi. Its overall surface area when villi are stretched is approximately 30 m^2, which is the size of half a badminton court!

In this activity, we will assume that the small intestine has a smooth internal surface (no villi) and use a model to **calculate** its surface area. We will then **compare** it with the true surface of the small intestine to appreciate the importance of villi in absorption.

Measuring the surface area of the small intestine

The small intestine's shape resembles that of a hollow tube. By using an open-ended cylinder as a model of the intestine, we can **calculate** its inside surface area (see Figure 6.12).



■ **Figure 6.12** A hollow cylinder becomes a rectangle when opened flat

Cylinders have a length and a diameter. When opened up, an open-ended cylinder becomes a rectangle. The height of the cylinder becomes its length (L) and the **circumference** of the top and bottom circular edges of the cylinder become the width of the rectangle (W).

Equipment

- **1 × cardboard cylinder (use the cardboard inner tube of a toilet roll or a kitchen towel roll)**
- **A pair of scissors**
- **A 30 cm ruler**
- **A calculator**

Procedure

1. **Measure and record the length (L) and the diameter of the cylinder.**
2. **Cut a straight line along the length of the cylinder to open it up into a rectangle as shown in Figure 6.12.**
3. **Measure the width of your rectangle. (Note that this is also the circumference of the top of the cylinder.)**

HINT

It is not always possible to open cylinders up into rectangles to measure their surface area. In this case, you could use the diameter (D) of the top circle of your cylinder to calculate its circumference ($C = \pi \times D$).

4. **Now that you know the length (L) and the width (W) of your rectangle, calculate its area.**
5. **By using the above model and procedure, and assuming that the length of the small intestine is 5 m and its diameter is 3 cm, calculate the surface area (SA) of this smooth small intestine.**

Processing results

If we stretch out the villi in the small intestine, the true surface area is estimated to be approximately 30 m^2. **Calculate** the ratio between the true surface area (TA) and the smooth surface area (SA) like this:

$$\text{ratio} = \frac{TA}{SA}$$

Interpret the results of your ratio calculations.

Explain (using scientific reasoning) the importance of villi in the efficient absorption of nutrients from the food we eat.

State the relationship between the number of villi per square centimetre and the overall surface area of the small intestine.

In your class, **discuss** the consequences on diet of the hypothetical idea that humans have:

a **half the number of villi they currently possess**
b **double the number of villi they currently possess.**

Discuss the possible economical, environmental and social implications of such changes in human anatomy.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding, Criterion C: Processing and evaluating and Criterion D: Reflecting on the impacts of science.

Why does pH matter to us?

You have seen how pH changes along the digestive system so that enzymes work properly. Do you think that maintaining a certain pH level elsewhere in the body is as important? Are there other factors that need to be maintained at a constant level? How does the body do that?

ACTIVITY: Enzyme detectives!

ATL

- Critical-thinking skills: Interpret data; Draw reasonable conclusions
- Creative-thinking skills: Generate testable hypotheses

Background

Gastroesophageal reflux disease (GERD), sometimes referred to as heartburn, is caused by chemical and physical changes that occur in the upper level of the digestive system. It was long thought that problems in the stomach are solely caused by the excess production of HCl, triggered by stress and eating certain foods such as fried food. However, modern medicine shows that there could be other related factors such as an infection of the stomach lining with the bacterium *Helicobacter pylori* or a change in the shape and the position of the stomach called hiatal hernia. Treatments for excess acid (antacids) are readily available to the public over the counter. Although many of these treatments are effective in relieving temporary excess acid in the stomach, there could be serious side-effects if they are misused.

Task

Your teacher has asked the laboratory technician to prepare a protease solution containing either pepsin or trypsin by diluting the powdered form of the enzymes in water. The solution is labelled with an X and your task is to identify its nature. Remember that each of these proteases has a different optimum pH of action. You will use egg white, which contains the protein albumen, as the substrate in this experiment.

Inquiry question: How will you identify the nature of the protease enzyme used in this experiment? What variables will you be changing, measuring or keeping the same? Write a question that links the independent variable to the dependent variable.

Hypothesis: Formulate and **explain** a testable hypothesis to answer your inquiry question using correct scientific reasoning.

Suggested materials

- **500 cm³ beaker**
- **Measuring cylinder**
- **Water bath**
- **Sieve**
- **Test tubes (depending on your choice of pH values to test)**
- **5 cm³ disposable pipettes (same number as the test tubes)**
- **Stop-clock**
- **Rubber bungs**
- **Buffer solutions for the chosen pH ranges**
- **Biuret indicator**

Figure 6.13 Biuret test for protein (left tube: negative result, right tube: positive result)

Suggested method

Preparing the egg white (protein) solution

1. **In a 500 cm³ beaker, separate the egg white from the yolk; keep the egg white.**
2. **With a measuring cylinder, measure the volume of the egg white obtained then pour it back into the beaker.**

3 **Add 9 volumes of water to the egg white and mix gently to make a homogenous solution.**
4 **Put the beaker in a water bath at around 70 °C and continue to stir with a glass rod for about 7 minutes. You will obtain a cloudy solution. (Do not boil the solution.)**
5 **Filter the resulting solution through a sieve to remove large chunks of egg white. You should now obtain an opaque/cloudy suspension.**
6 **Label your solution clearly.**

Choosing the different pH solutions

Based on the information given in Table 6.6, what pH ranges will you use? You may agree for each group to test one separate pH value then pool the results. Alternatively, you could use the skills you learnt about acids and bases earlier in this chapter to prepare dilute solutions of weak acids and bases that will act as buffer solutions.

Safety: You will be using a dilute solution of a protease enzyme which is considered low hazard. Powdered enzymes are considered harmful. You will also be using buffer solutions of various pH containing diluted acids and bases. These must be handled with care. Wear eye protection and gloves when handling the buffer solutions and the enzymes. Observe laboratory safety rules when using the water bath at 70 °C.

Adding the egg white solution to the enzyme

1 **Add 10 cm³ of the protein suspension you prepared earlier to your test tubes. How will you label your test tubes so that you don't get mixed up?**
2 **Using a different pipette each time, add 5 cm³ of the desired pH buffer solution.**
3 **Cover the test tubes with rubber bungs then mix them well.**
4 **How will you verify that the solutions in the test tubes are at the correct pH?**
5 **Using a different pipette each time, add 5 cm³ of the protease enzyme solution X and shake gently.**
6 **Allow to stand in a water bath at 37 °C and start the stop-clock. The results may take a few hours to appear but keep observing the solution in the test tubes for any changes in colour or transparency. Record the time it takes for the colour to become clear in each test tube.**
7 **As an additional test, you may add 1–2 cm³ of Biuret indicator to each test tube and mix (see Figure 6.13). Which colour will indicate the presence of protein and which one will show its absence in the solution?**
8 **How will you confirm the reliability of your results?**
9 **Once you have collected, organized, transformed and presented your observations and your data into a table, plot a suitable graph of the mean of your results showing the effect of pH on the activity of the enzyme. Your graph must include units and axes labels.**

Interpretation and conclusion

These guiding questions will help you to **interpret** your results and draw a conclusion.

- **In which test tubes was the protein digested?**
- **From your graph, at which pH value was the activity of the enzyme the highest?**
- **What does this tell you about the nature of this enzyme based on what you learnt in this chapter? Justify your answer using scientific reasoning.**
- **In which organ in the digestive system does this enzyme perform its functions?**

Evaluate your hypothesis and method, **suggest** improvements you could have made and any further inquiry you could follow.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion B: Inquiring and designing and Criterion C: Processing and evaluating.

ACTIVITY: A pH map of your body!

ATL

- Information literacy skills: Access information to be informed and inform others
- Creative-thinking skills: Apply existing knowledge to generate new ideas, products or processes

In groups of 3–4 students, carry out the following tasks.

1 **Find an A3 sheet or a larger piece of paper to draw a poster of the human body. You may download/print a small picture from the internet and scale it up. You must draw key organs such as the ones shown in Figure 6.14.**

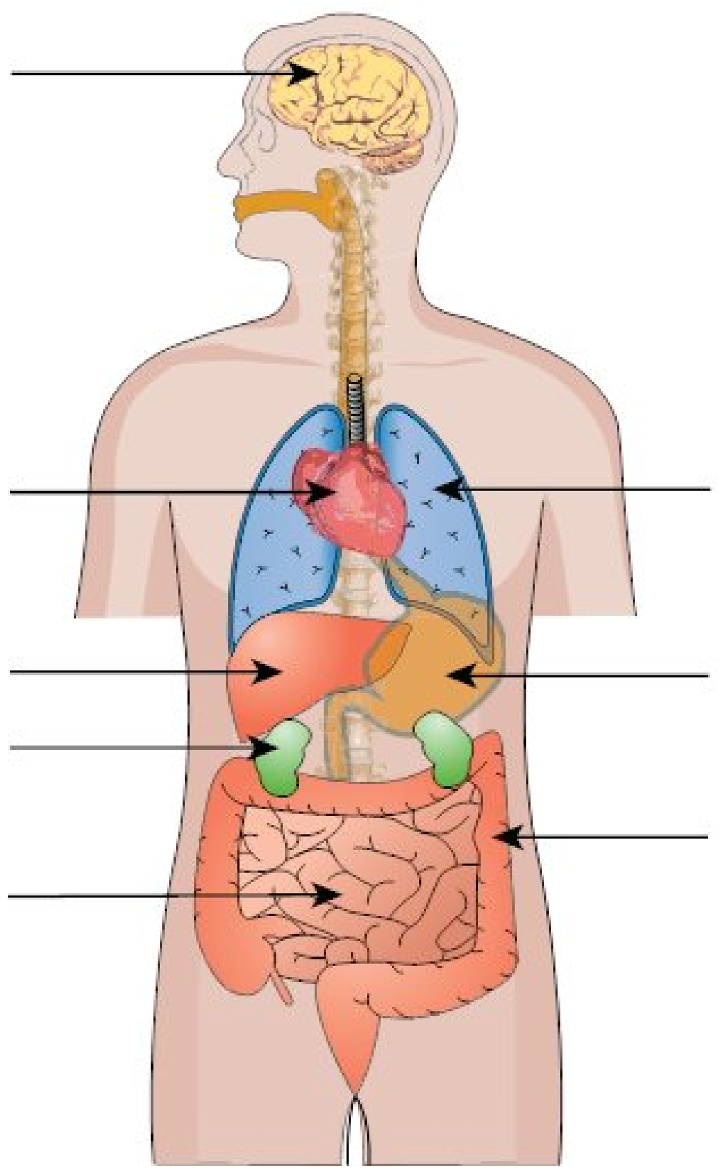


Figure 6.14 Diagram of the human body showing key organs

2 **Consult Table 6.6 and record pH values for the listed digestive organs where there is enzyme activity.**

3 **Use your browser to search for pH values in other digestive organs where no major enzyme activity happens, such as the large intestine and the gallbladder. Extend your search to other key organs/tissues/fluids in the body such as: the skin, the blood, muscles, the bladder, kidneys, fluid surrounding the brain, the vagina, testicles, seminal vesicles and lymph.**

4 **Write the pH values on sticky notes and place them on your human body poster. What conclusion can you make about the pH across the human body?**

5 **Conduct another search and use information from this chapter to pinpoint the locations in the digestive system where neutralization happens.**

6 **The team that finishes first will display its poster to the rest of the class so that other teams can stick their pH values when done. As a class, discuss your findings. Are there any differences? What might be the cause?**

7 **Each group should now select one of the pH locations on the poster and conduct further research on how the pH is maintained at a constant level. Analyse and evaluate the information you find to make a judgment about how the body maintains its internal acid/base balance.**

8 **Next to the pH values, add a summary of the information you found for each location. You may prefer to draw arrows pointing at each of the locations instead. You have now completed your human body pH map. Is there another way to display this information?**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

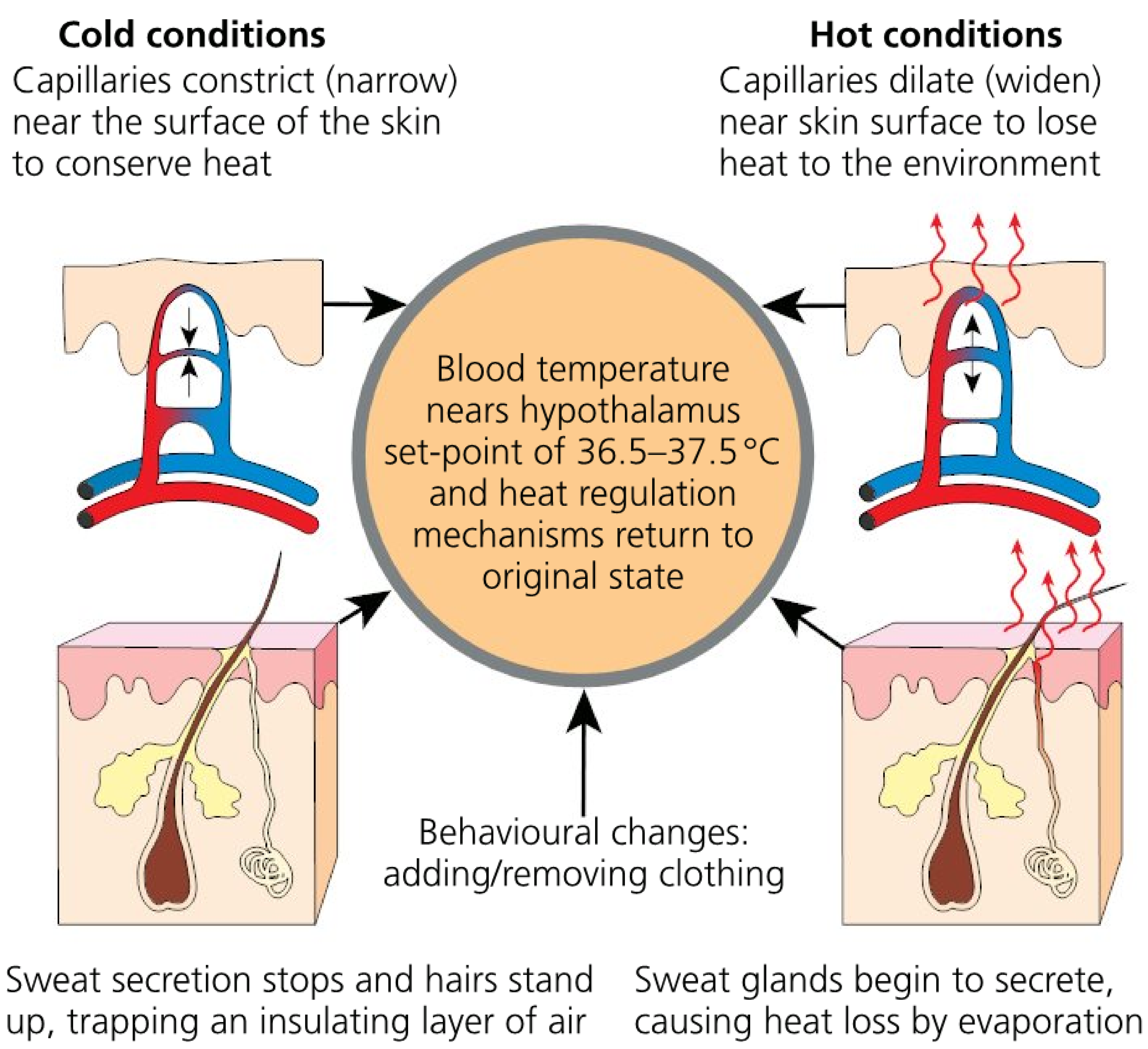
EXTENSION

Our skin has a pH between 4 and 5. Enter search terms: **skin pH, maintain, balance, microflora** to find out both how the skin maintains this acidity and what benefit it has to human health. You could also find out how using soaps and cosmetic products may affect our skin.

How do organisms maintain balance when adapting to changes inside and outside the body?

In complex animals, certain conditions need to be kept balanced in internal environments regardless of the changes in the outside environment. Examples are: body temperature (37 °C in humans), sugar (see Figure 6.16), CO_2, water and electrolyte levels in the blood and in fluids surrounding tissues. All the processes that happen in the body to maintain these factors in balance are called homeostasis. Homeostasis is a complex process that requires all body systems to work together. There are three components that help the body achieve its balance (see Figure 6.15):

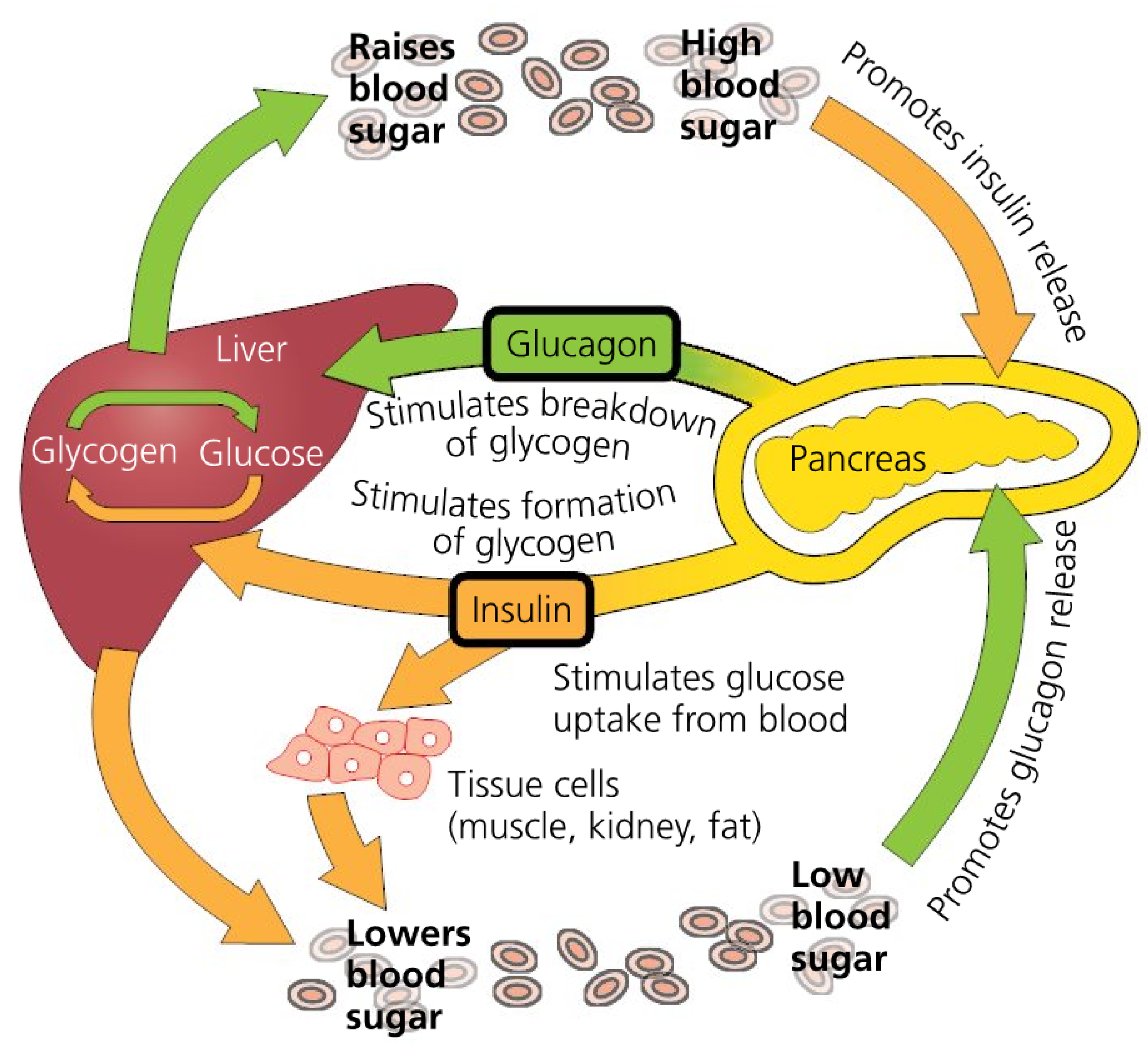
1. A receptor to detect change inside or outside the body. Can you think of an example?
2. A control centre to process sensory information and coordinate action. This is the central nervous system.
3. An effector to direct an appropriate response, such as sweating and vasodilation to regulate temperature.



■ **Figure 6.15** Thermoregulation in humans

THINK–PAIR–SHARE

Carefully examine Figure 6.15. **Think** about how the body responds to changes in temperature. **Share** your thoughts with your partner and **discuss** how the three components needed for homeostasis are shown here. Now **share** your ideas with the rest of the class.



■ **Figure 6.16** The control of blood sugar levels in the human body

Are modern medical advances and diagnostic methods accessible to all?

Reaching a diagnosis requires the use of various methods and procedures called diagnostic techniques. These have seen rapid development in the past century from when doctors relied on basic physical examination skills and tools. Such developments are taking place thanks to new technologies that allow us to investigate the cause and location of disease with a high degree of precision and accuracy. Some modern diagnosis methods include:

- laboratory tests (blood, urine, semen, lymph, stools)
- imaging techniques such as X-rays, ultrasound, CT scans
- nuclear medicine such as MRI and PET and endoscopy

Unfortunately, many populations in poorer countries do not have access to these technologies and continue to suffer and die from preventable diseases.

WHY IS CHILDHOOD DIARRHOEA STILL KILLING SO MANY CHILDREN AROUND THE WORLD?

The map in Figure 6.17 shows the estimated number of children killed in 2015 by diarrhoeal disease. Diarrhoea accounts for 9 per cent of deaths among children under the age of 5 years around the world according to **UNICEF**. This means that over 1400 young children die each day despite the simplicity of treatment for this disease.

■ **Figure 6.17** A map showing the percentage of deaths among children under age 5 attributable to diarrhoea, 2015

! Take action: Find out and take action on childhood diarrhoea!

ATL

- Critical-thinking skills: Interpret data
- Reflection skills: Consider ethical, cultural and environmental implications
- Collaboration skills: Practise empathy

! In this activity you will process and **interpret** data obtained from the World Health Organization (WHO). Table 6.8 shows the top 15 countries ranked according to the number of deaths in children under 5 years due to diarrhoea in 2004. Collectively, they account for 73 per cent of all deaths of under-5s worldwide.

- Transfer the number of deaths per country shown in Table 6.8 to a spreadsheet. **Calculate** the percentage deaths due to diarrhoea in each country out of the total value for the 15 countries shown.
- **Plot** a graph to compare the percentage deaths in these 15 countries. Which graph is more suitable for this type of categoric data? Remember that the independent variable must be on the x-axis and the dependent variable on the y-axis.
- **Interpret** the data to **deduce** which country accounts for the highest number of deaths according to your graph.
- Now use the information given in the background section of this activity to **calculate** the total number of deaths from diarrhoea around the world.
- **Calculate** the percentage deaths in each country out of the total number of deaths in the world.

- **Present** your percentage calculations in a suitable graph. Which graph will you use this time?

Country	WHO subregion	Deaths due to diarrhoea (thousands)
India	SEAR D	535
Nigeria	AFR D	175
Democratic Republic of the Congo	AFR E	95
Ethiopia	AFR E	86
Pakistan	EMR D	77
China	WPR B	74
Bangladesh	SEAR D	69
Afghanistan	EMR D	65
Indonesia	SEAR B	39
Angola	AFR D	34
Niger	AFR D	33
Uganda	AFR E	28
Myanmar	SEAR D	26
United Republic of Tanzania	AFR E	25
Mali	AFR D	24
Total of 15 countries		**1384**

■ **Table 6.8** Number of deaths in children under 5 years in top ranking countries in 2004. Source: WHO, 2004

- **Interpret** and **explain** the data from both your graphs using correct scientific reasoning. You may conduct further research on a statistical website such as **www.gapminder.org/** to link and **explore** some factors in specific countries of your choice. For example, you could search for the level of education or socio-economic situation in your selected country.

! Studies have shown that some specific risk factors are associated with childhood diarrhoea in these countries. Read the results section of this scientific paper: **www.ncbi.nlm.nih.gov/pmc/articles/PMC4021233/**

! Visit this website: **https://data.unicef.org/topic/child-health/diarrhoeal-disease/**

! Search further by using these search terms: **childhood diarrhoea, mortality, risk factors**.

! While conducting your search, you will acquire a large amount of information. It can be challenging to make meaningful connections between such information. Use a visible thinking routine such as Generate–Sort–Connect–Elaborate to help **organize** your research.

! If you were a group of community volunteers working for a community health organization, how might you take action to help tackle some of the causes of the high mortality rates that you learnt about?

■ **Figure 6.18** Mothers in Juba, South Sudan, being shown how to prepare oral rehabilitation salts (ORS) by a community health volunteer

- In a small group of students, choose one area from the categories of factors you generated above.
- Once you have picked an area of action, think of the best way for your group to help tackle the issue: it could be through an awareness campaign aimed at families that live in most affected regions; leaflets or letters to local authorities to help improve living conditions. You could also **design** a product such as a better water filtering system, a cheap hand sanitizing device or a simple sewage treatment facility.
- **Explain** your product or chosen mode of action to the class and **evaluate** the limitations or difficulties you may face.
- **Apply** scientific language to communicate your ideas; include any graphs or statistical data you used to back up your arguments. Do not forget to **document** your sources completely.

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science and Criterion C: Processing and evaluating.

SOME REVIEW PROBLEMS TO TRY

1 **State** where starch, protein and fat are broken down in the digestive system and **state** the names of the enzymes that break them down.

2 **Outline** the role of the liver and the gall bladder in digesting fats.

3 **State** the name of the process by which food is moved down through the digestive system.

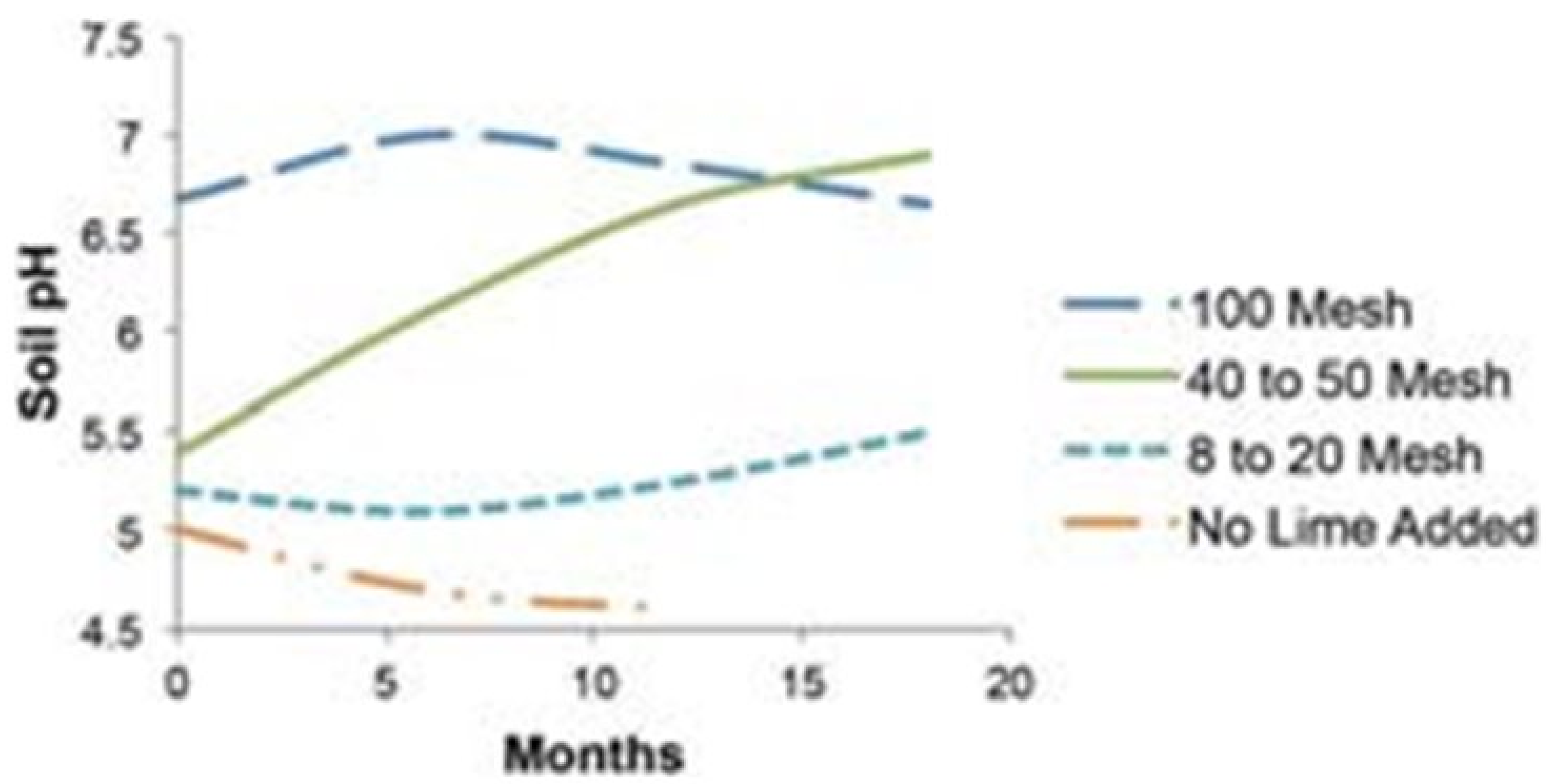
4 The pancreas has a role in digestion and in regulating the sugar levels in the blood. Figure 6.16 on page 161 summarizes how glucose levels are kept constant.

- a Use the diagram to help you complete these tasks:
  - i **State** in which form and where glucose is stored in the body.
  - ii **Describe** what happens after someone drinks a soft drink with a high amount of sugar.
  - iii **Describe** what happens after someone runs a marathon and uses up a lot of energy to fuel the muscle cells.
  - iv **State** the name of the process by which the body keeps the sugar level and other conditions balanced in the body.
- b In people suffering from Type 1 diabetes, the cells that produce insulin in the pancreas are destroyed by an autoimmune process. **Describe** how this affects the sugar levels in the blood by using the information in the diagram.
- c Injecting controlled levels of insulin helps these patients to reduce their blood sugar and bring it to the required levels. **Explain** the risk associated with injecting too much or too little insulin into the body.

5
- a **State** whether the following salts are soluble or insoluble:
  - i potassium sulfate
  - ii lead chloride
  - iii sodium carbonate
  - iv calcium phosphate
  - v silver sulfate.
- b **Deduce** the starting materials for making the insoluble salts identified in part (a).
- c A student has five bottles of acid, A, B, C, D and E. The student knows that bottle C has a pH of 5 but the rest of the bottles are unlabelled. She is able to measure the hydrogen ion concentration and compare it to C, getting the following results:
  - The concentration of A is 1000 times greater than that of solution C.
  - The concentration of B is 10 times lower than that of solution A.
  - The concentration of D is 10 000 times lower than that of solution B.
  - The concentration of E is 100 000 times lower than that of solution B.

  State which solution is neutral, **explaining** your answer.
- d Soil pH naturally decreases over time which can lead to changes in its chemical and biological properties. This increase in the acidity of the soil can be combated by adding a liming material; the amount that is added will depend on the optimum pH of the soil for the specific crop.

  Figure 6.19 shows how the pH of the soil changed over time (the rate of reaction) using different-sized particles of liming agent. The mesh size indicates the size of the particles; the higher the mesh number, the smaller the particles.



■ **Figure 6.19** Graph to show how the mesh size (size of liming material particle) affects the time it takes for the pH to increase

- **i** **Describe** the general relationship between mesh size and rate of neutralization. **Analyse** and **evaluate** the data to **determine** the optimum mesh size for bringing about a pH change quickly (over a few weeks) and over a longer period of 18 months.
- **ii** An apprentice working on a farm has to decide between adding lime (calcium carbonate) or gypsum (calcium sulfate) to the soil. **Explain** which compound he should select, supporting your decision with scientific reasoning.

Reflection

In this chapter we have **defined** the terms acid and base, looking at how the definitions have developed over time. We have **described** how to test whether a substance is an acid or a base, as well as **summarizing** what affects the pH of a substance. We have **defined** neutralization and learnt how to **formulate** word and symbol equations for the reactions of acids with bases and metals. We have **stated** the rules that determine whether a salt is soluble or insoluble and **described** experimental methods to make salts. We have **outlined** what constitutes a balanced diet and **described** how the body digests the food we eat. We have **applied** our knowledge to distinguish between mechanical and chemical digestion and **described** the relationship between form and function in the digestive system. We have **explained** the importance of maintaining a balanced pH in the digestive system and **discussed** the effect of disturbing this balance on the work of some digestive enzymes. We have **discussed** the importance of balancing certain conditions and seen how the body achieves this through homeostasis. Finally, we have **evaluated** the accessibility of modern medical diagnostic methods and treatments to other parts of the world and **suggested** how we can help to tackle some of the issues related to digestive problems.

<table>
<tr><th colspan="6">Use this table to reflect on your own learning in this chapter</th></tr>
<tr><td>Questions we asked</td><td>Answers we found</td><td colspan="4">Any further questions now?</td></tr>
<tr><td>Factual</td><td></td><td colspan="4"></td></tr>
<tr><td>Conceptual</td><td></td><td colspan="4"></td></tr>
<tr><td>Debatable</td><td></td><td colspan="4"></td></tr>
<tr><td rowspan="2">Approaches to learning you used in this chapter</td><td rowspan="2">Description – what new skills did you learn?</td><td colspan="4">How well did you master the skills?</td></tr>
<tr><td>Novice</td><td>Learner</td><td>Practitioner</td><td>Expert</td></tr>
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<tr><td>Learner profile attribute(s)</td><td colspan="5">Reflect on the importance of being balanced for your learning in this chapter</td></tr>
<tr><td>Balanced</td><td colspan="5"></td></tr>
</table>

7 How do machines make our lives better?

The way that nature uses **systems** of force for **movement** inspires mankind to **create** machines and **extend** our abilities.

CONSIDER THESE QUESTIONS:

Factual: What structures and systems enable humans to move and perform everyday functions?

Conceptual: How can the understanding and application of mechanics improve lives? How are force and motion related?

Debatable: To what extent have scientists learnt from nature? Can robots replace humans?

Now **share and compare** your thoughts and ideas with your partner or with the whole class.

These Approaches to Learning (ATL) skills will be useful …

- Creative-thinking skills
- Information literacy skills
- Collaboration skills
- Communication skills
- Critical-thinking skills

Assessment opportunities in this chapter:

The activities in this chapter will help you develop and evaluate your learning in these MYP Sciences learning objectives:

Criterion A: Knowing and understanding

Criterion B: Inquiring and designing

Criterion C: Processing and evaluating

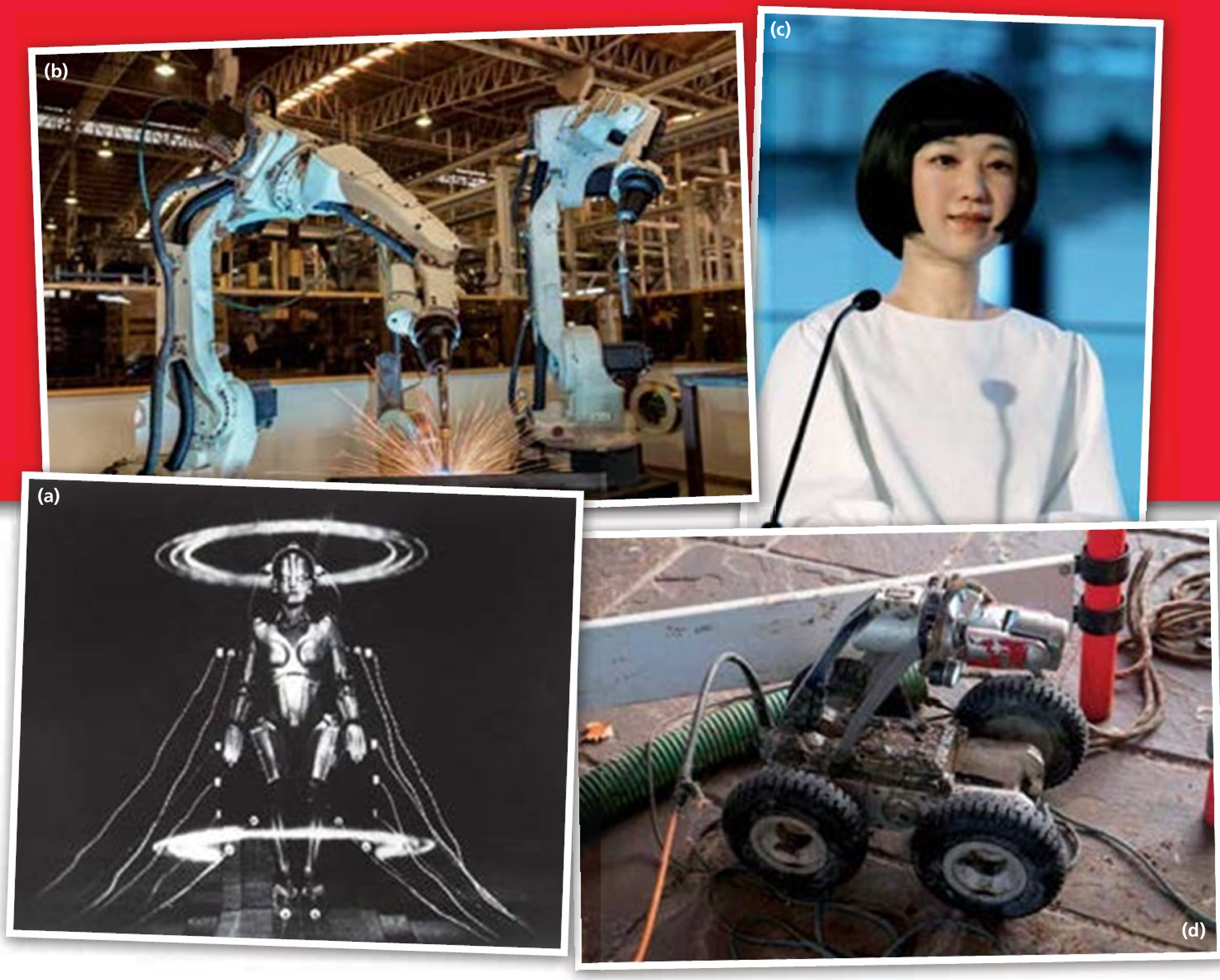
Criterion D: Reflecting on the impacts of science

KEY WORDS

advantage
effort
load
shot-put
spring

IN THIS CHAPTER, WE WILL …

- **Find out** how the human musculoskeletal system works and how we can analyse its function through an understanding of mechanics.
- **Explore** how much the human body can do, the ways in which machines can be used to assist people in their everyday lives, and consider the future function of robots.
- **Take action** to propose a robotics solution to a real-life problem and pitch it to investors.



■ **Figure 7.1** Robots: (a) a science fiction robot from the 1927 film *Metropolis*; (b) an industrial production line; (c) Professor Hiroshi Ishiguro's Kodomoroid android; (d) a sewer inspection robot

● We will reflect on this learner profile attribute …

- Thinkers – we will consider how different ideas about forces and motion have arisen through observations of natural systems such as the human body.

SEE–THINK–WONDER

Look at the images of robots in Figure 7.1. What do you **see**? What do the images make you **think**? What do the images make you **wonder**?

In *MYP Sciences by Concept 3:* Chapter 1 we concluded our exploration of machines with some thoughts about their future. Machines assist us in our everyday lives; but will machines at some point become completely autonomous, so that they no longer require our input? Robots are machines that can operate with a degree of autonomy, without requiring instruction from humans at every step. The images in Figure 7.1 are different kinds of robot – some more autonomous than others.

All these robots rely on an understanding of mechanics and, in the case of **androids**, their design is inspired directly by the mechanics of the human body. In this chapter we will explore how the human body is able to perform physical functions, from everyday situations to the most demanding – such as in Olympic sports. We will also consider how the performance of the human body can be assisted, and ultimately improved, by mechanical devices.

What structures and systems enable humans to move and perform everyday functions?

HOW MUCH CAN THE HUMAN BODY DO?

Do you enjoy exercise? Testing your abilities and the capacity of your body can be a lot of fun and if you organize your exercise regime by setting personal targets, it can also be very rewarding. Athletics allows us to find out just how much the human body can achieve.

Athletes train for years to qualify for competition in the Olympics, and their training is now highly informed by the science of biomechanics and physiology.

One of the most anticipated events in the Olympic Games is the 100 m sprint final. Table 7.1 shows the times achieved by runners in two sets of Olympic Games.

Unless we are lucky enough to have tickets to watch the race, it can be quite hard to gain a sense of just how fast these runners go. One simple way to calculate this is to compare their average speeds measured in metres per second or $m\,s^{-1}$.

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

Worked example

To work out Usain Bolt's greatest average speed, we need values for distance and time. We know that the distance for the race is 100 m. Bolt's shortest time for the race was in 2012 so

$$\text{speed} = \frac{100}{9.63}$$

$$\text{speed} = 10.4\,m\,s^{-1}$$

We most commonly experience speed when riding in vehicles, and the speeds are then measured in kilometres per hour or $km\,h^{-1}$ (or miles per hour if you live in a country that uses imperial measurements). To convert metres per second to kilometres per hour

$$\text{speed }(km\,h^{-1}) = \text{speed }(m\,s^{-1}) \times \frac{60 \times 60}{1000}$$

since there are 3600 s in one hour and 1000 m in 1 km.

This gives us an average speed for Bolt's 2012 race of

$$\text{speed} = 10.4\,m\,s^{-1} = 37.4\,km\,h^{-1}$$

DISCUSS

What does this value tell us? What does this value *not* tell us?

Hint

Would Bolt have been running at this speed the whole time?

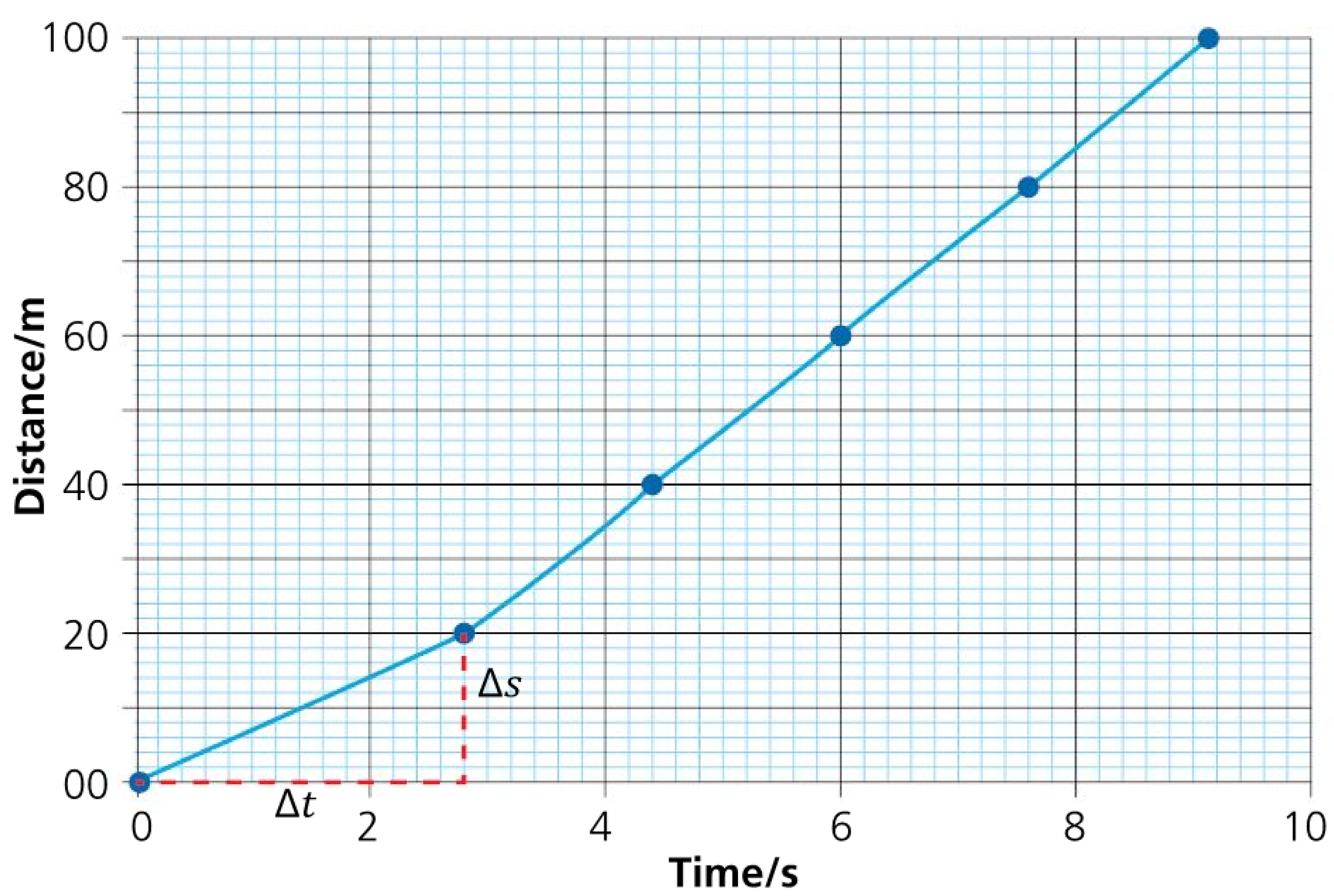
You may have realized that this average value doesn't tell us how Bolt's speed changed *during* the race. Naturally, it takes time for the runner to reach maximum speed and they may not maintain that speed. We can see this if we measure Bolt's times to run different intervals in the race, for example every 20 m (Table 7.2).

We can then plot these values onto a graph showing distance run against time taken (Figure 7.3); a distance–time graph.

Athlete	Country	Time(s) Rio 2016 (placement)	Time(s) London 2012 (placement)
Usain Bolt	Jamaica	9.81 (1)	9.63 (1)
Justin Gatlin	USA	9.89 (2)	9.79 (3)
Andre de Grasse	Canada	9.91 (3)	
Yohan Blake	Jamaica	9.93 (4)	9.75 (2)
Akani Simbine	Republic South Africa	9.94 (5)	

Table 7.1 Top placed men's final 100 m sprint times at two successive Olympics (Data source: **www.olympic.org**)

■ **Figure 7.2** Usain Bolt, winner of the 100 m sprint final at the 2008, 2012 and 2016 Olympic Games



■ **Figure 7.3** Distance–time graph for Usain Bolt's 100 m final at the London Olympic Games, 2012

Athlete	Start	20 m	40 m	60 m	80 m	100 m
Bolt	0	2.93	4.69	6.35	7.96	9.63

■ **Table 7.2** Distance–time measurements for Usain Bolt, 100 m sprint final, London 2012 (Data source: Mackenzie, B. (2001) *Sprinting*)

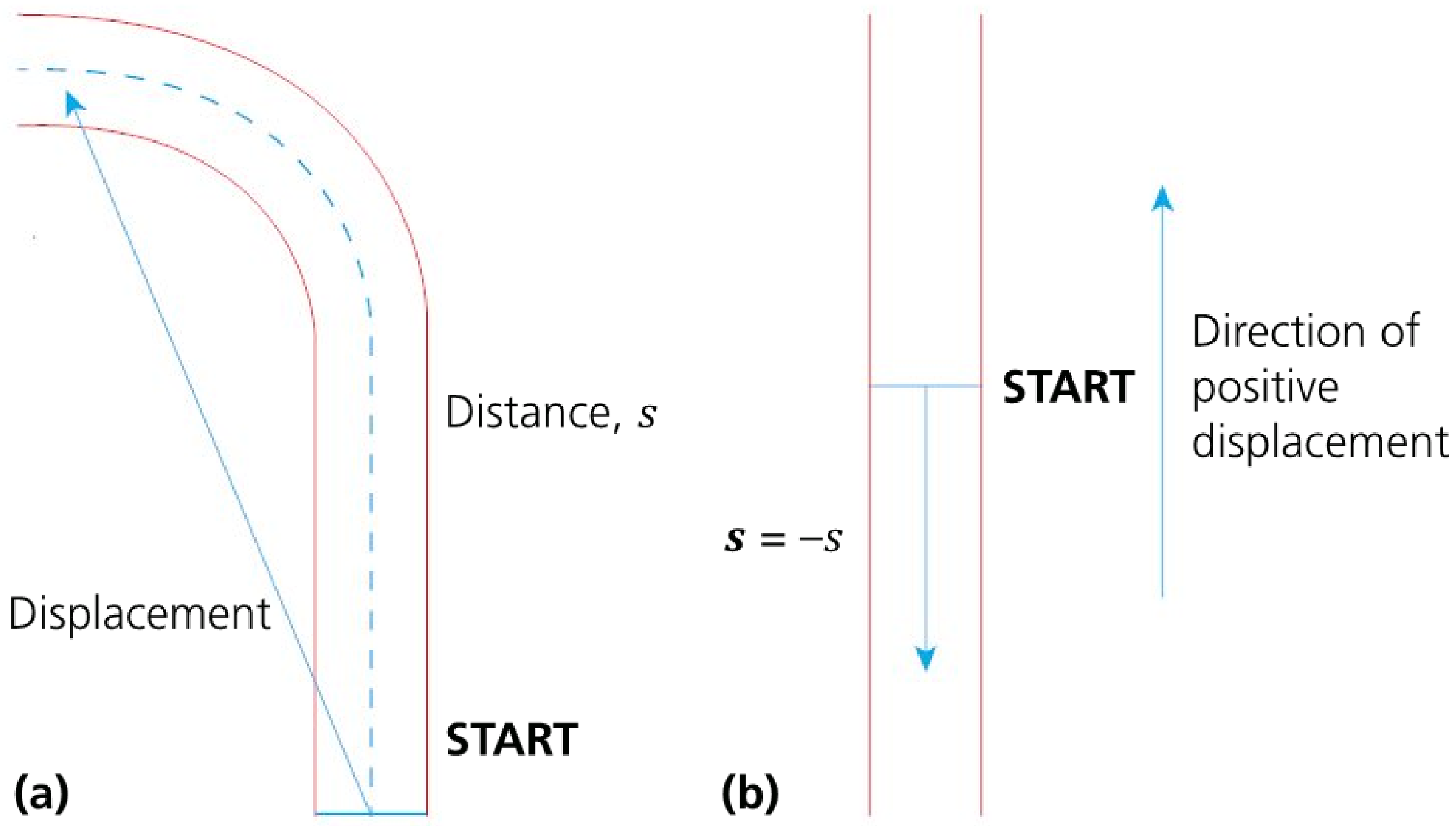
If the speed is constant, the runner will cover the same distance every second. Consequently, the line on a speed–time graph will increase in a linear fashion. We can see that for Bolt this was the case for most of the race: from 3.00 s to the end he was running at close to his maximum speed. However, at the beginning of the race, the graph curves upward and this indicates that Bolt was running a greater distance within each subsequent second.

When we calculate the *average* speed for a section of the race, we are taking the change in distance, shown as Δs on the graph, and we are dividing it by the time taken, Δt. You will recall from Chapter 2 that this is the slope or *gradient* of the line, averaged over this period.

DISCUSS

What evidence is there in the distance–time graph for Bolt's 2012 race that his speed changed during the race?

The 100 m race is run over a straight section of the track, but what about races that run on curved sections? In these cases the runner's direction is also changing. Going around a curve means they are still running the full distance, but the runner's net distance from the start or end point of the race will not increase at the same rate. To make this distinction, the net distance from a particular point is called the displacement (Figure 7.4).



■ **Figure 7.4** Distance and displacement for a curved track race: (a) the displacement describes the net distance of the runner from the start point, including direction, and is a vector; (b) if the runner runs the wrong way, their displacement is negative

Since it includes the direction of travel, displacement, s, can be negative – for example if the runner was confused and began to run in the wrong direction at the beginning of the race! Generally, however, displacement is defined as positive in the upward direction or to the right on a two-dimensional plane. You may have realized that this makes displacement a **vector quantity** and for this reason, it is denoted using **bold type**. You may know from mathematics that displacement can also be shown as $\vec{s}$.

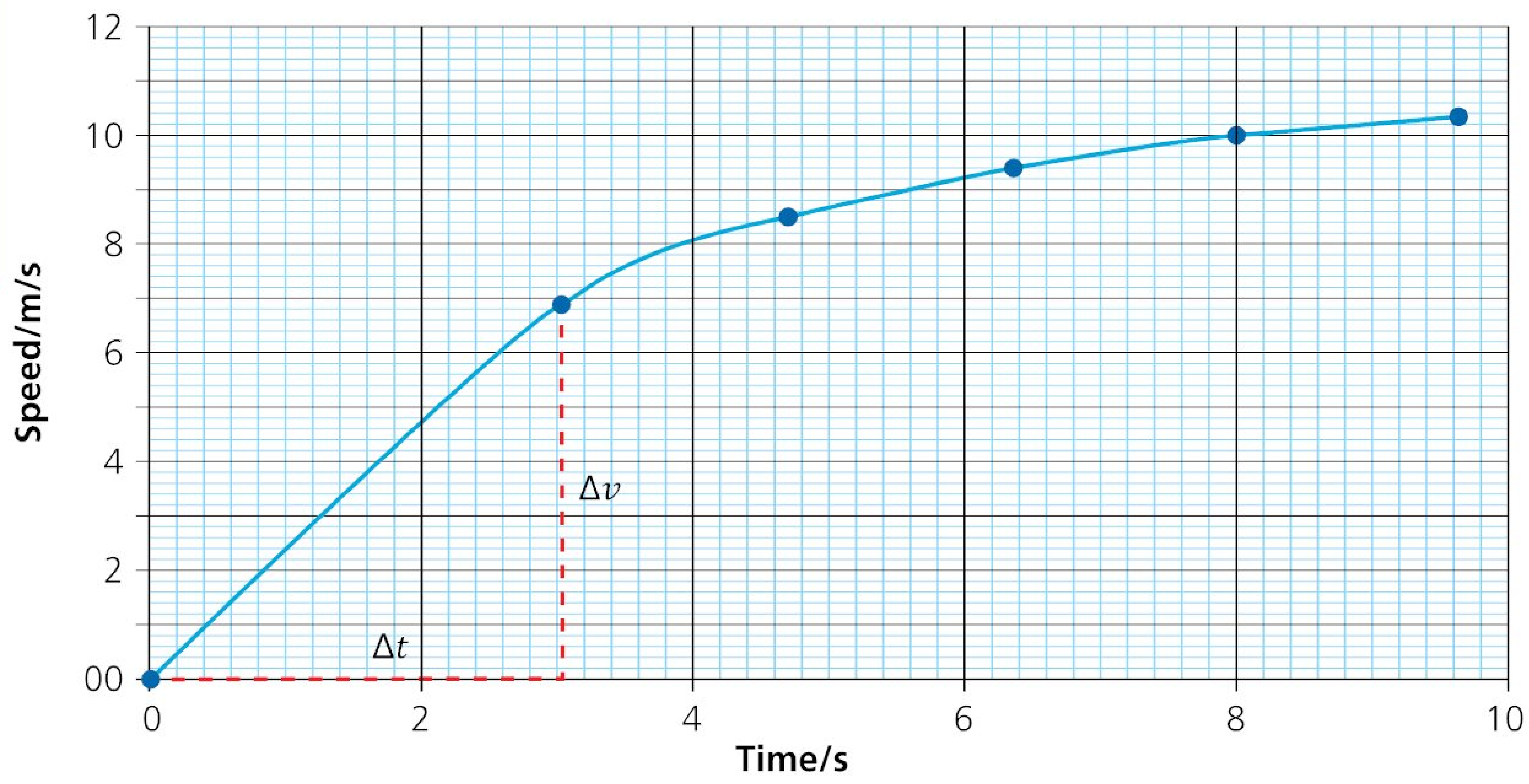
We can calculate the vector quantity for the average displacement over a period of time. This is called the velocity, $\mathbf{v}$ or $\vec{v}$.

$$\text{velocity} = \frac{\text{displacement}}{\text{time}}$$

$$\mathbf{v} = \frac{\mathbf{s}}{t}$$

DISCUSS

What about time? Should time be shown as a vector or a scalar?



■ **Figure 7.5** A speed–time graph for Usain Bolt's 100 m final at the London Olympic Games, 2012

■ **Figure 7.6** Traffic police use radar guns to measure the speed of traffic

While the distinction between speed and velocity might seem a little abstract right now, we will see that it becomes important when we consider acceleration.

We can now present the information about Bolt's 2012 race as a speed–time graph (Figure 7.5).

When shown this way we can see more clearly how Bolt's speed changed during the race. At the start his speed increased rapidly and later on it continued to increase, but at a lower rate. What does the slope of this graph represent? If we calculate this for a particular part of the graph, we obtain the average acceleration, which is the change in velocity over a period of time.

$$\text{average acceleration} = \frac{\text{change in velocity}}{\text{time}}$$

$$\boldsymbol{a} = \frac{\boldsymbol{v}_2 - \boldsymbol{v}_1}{t_2 - t_1}$$

We use the Greek letter delta (Δ) to mean 'change in' and this means we can write this equation in a shorter fashion:

$$\boldsymbol{a} = \frac{\Delta \boldsymbol{v}}{\Delta t}$$

Since velocity is measured in m s^{-1}, we now have the change in m s^{-1} every second, so the unit of acceleration is written as m s^{-2} or 'metres per second squared'.

Acceleration is always calculated using the velocity, not the speed. In the case of a straight-track race, like the 100 m sprint, this doesn't make any difference to the value obtained. However, when an object changes direction, its velocity changes, because velocity is a vector. This means that an object travelling in a circle is *accelerating* even though its speed in turning around the corner might remain constant. This has important implications for the way forces cause accelerations, as we will see shortly.

Worked example

What was Bolt's greatest average acceleration during the race?

Solution

We can see that this occurs where the slope of the graph is greatest, which we can estimate to be during the first three seconds of the race. Bolt's velocity at 3.0 s was $6.8\,\text{m s}^{-1}$.

$$\boldsymbol{a} = \frac{\Delta \boldsymbol{v}}{\Delta t}$$

$$\boldsymbol{a} = \frac{6.8 - 0}{3 - 0}$$

$$\boldsymbol{a} = 2.3\,\text{m s}^{-2}$$

ACTIVITY: Measuring traffic speed

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument; Evaluate evidence and arguments
- Collaboration skills: Delegate and share responsibility for decision-making; Work collaboratively in teams

Inquiry: How well do speed restrictions work?

Is there a traffic camera near to your school or a speed restriction sign? If you don't have a traffic camera or other speed restriction near to your school, you can still use this method to measure traffic speeds along a busy stretch of road. Are there signposts telling drivers where your school is located? Is there any other hazard warning? If so, use the method to see what effect the warnings have on driver behaviour.

You will need to work in a large group of 8–10 people. You should read the following instructions first and then **discuss** the points afterward.

Equipment

- Stopwatch or other accurate timer
- Long tape measure (10–20 m minimum)

Procedure

1. One member of your group will be the timer. They will also need two assistants: an observer and a recorder to write down times.
2. Position the other members of your group along the pavement (sidewalk) before and after the traffic camera, at regular intervals, for example 10 m or so. **Measure** the intervals with the tape measure.
3. Marker 1 is the person that the traffic passes *first.* Marker 1 identifies a particular vehicle and, when it passes them, raises their hand.
4. When marker 1 raises their hand, the observer says 'Start' and the timer starts the stopwatch.
5. As the vehicle passes each of the other markers in the group, they raise their hands. As they do so, the observer counts them off, saying '1 … 2 … 3 …' as the vehicle passes each of the markers.
6. The timer reads out the time for each marker; the recorder writes the time in a data table.
7. Repeat for a suitably large number of vehicles.

Before you begin, **discuss**:

- How many vehicles will be a suitable number?
- How will you **organize** the table for the recording of the raw data?

Hypothesis

Now individually make a hypothesis about the way that the traffic will behave in the area you are monitoring for the experiment. Be sure to refer to your experiment variables, for example: *I think that the times measured for the traffic will … because the traffic will …*

Analysing and interpreting

1. Use your raw data to **calculate** the speeds of the vehicles at each of the measurement points.
2. **Present** this information in your own graph of speed against time for all vehicles.
3. **Discuss** and then **outline** the information from your own graph:
   - Which vehicle changes speed most quickly? **Explain** how you decided.
   - **Interpret** your graph. **Identify** any times where the vehicles travel at constant speed.
   - **Calculate** the speed limit for the road in $m\,s^{-1}$ and mark this on the graph with a line. Remember you will need to convert the speed limit from the units used where you live to the standard scientific unit of $m\,s^{-1}$!
   - Use a vertical line to show on your graph the position of the traffic camera, speed restriction sign or similar.

Conclusion

Summarize your findings, referring closely to your data. **Explain** how you have interpreted the data to give information about the motion of the vehicles. **Describe** the effect of the speed camera.

Evaluation

1. **Outline** what problems (sources of error) there were with your experiment.
2. **Evaluate** how important (significant) each of these problems were.
3. **Suggest** how you could modify the design of your experiment to remove or lessen these problems.

Assessment opportunities

- This activity can be assessed using Criterion C: Processing and evaluating.

THE HUMAN MUSCULOSKELETAL SYSTEM

THINK–PAIR–SHARE

Look at Figure 7.7. **Think** how many different tissues this part of the human body is made up of. Which of these tissues is involved in movement? Which tissue is not shown in this image? **Share** your thoughts with your partner.

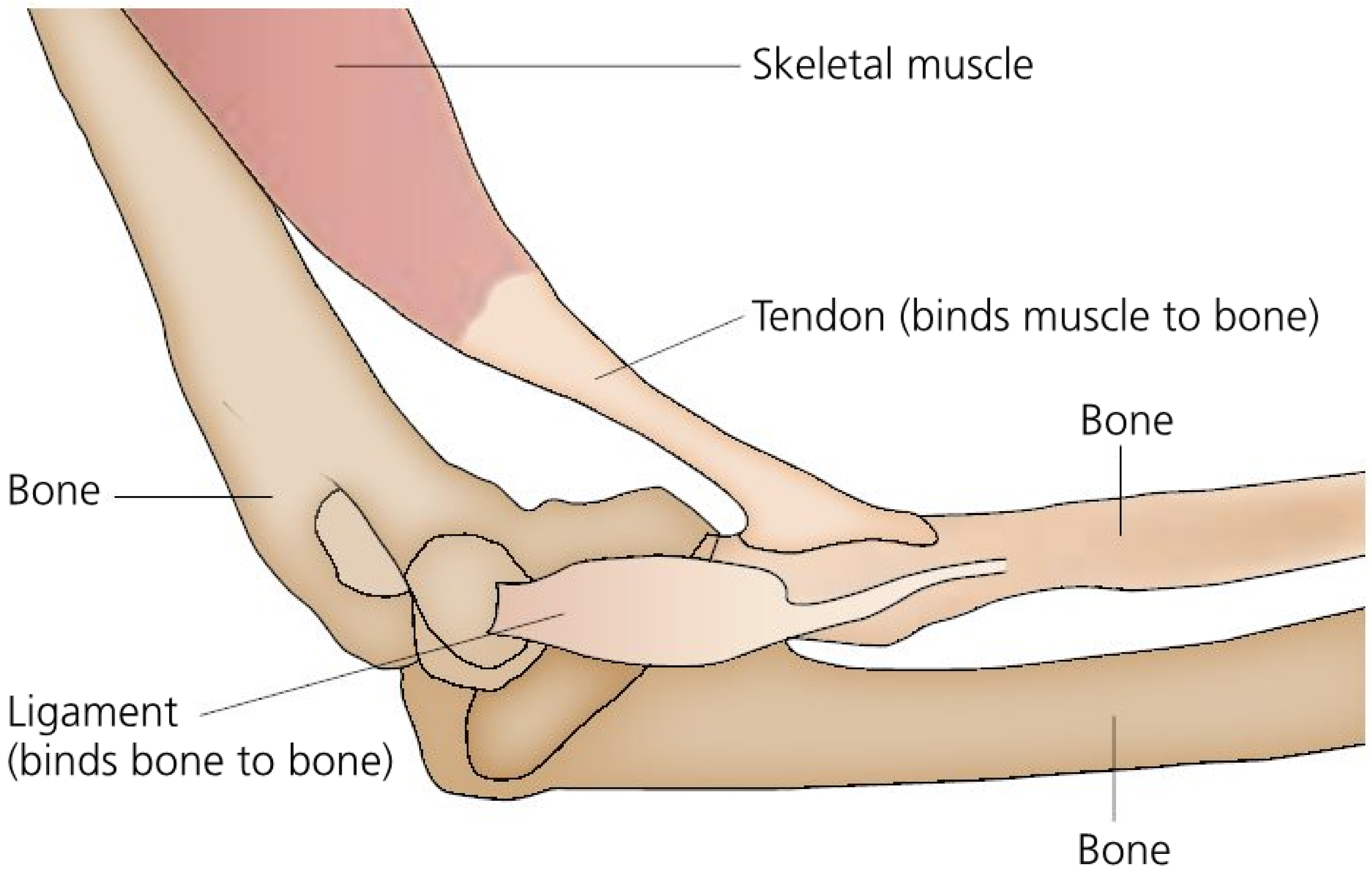
■ **Figure 7.7** Layers of muscle cover the human skeleton

Humans and most animals need to be on the move if they are to meet their biological needs. Movement in humans is facilitated by the musculoskeletal system, while other living things use different systems to change location. In this section, we will focus on the structures that enable the human body to move in ways we may take for granted, but which are in fact amazingly versatile.

Humans belong to the animal group called **vertebrates** (animals with a backbone). All vertebrates possess a bony internal skeleton to which muscles are attached with **tendons**. In adults, the human skeleton comprises 206 bones articulated at the point of **joints** which allow movement in different positions. **Ligaments** are tough and elastic tissues that hold the bones together (see Figure 7.8).

Because muscles and bones work together to allow movement, the muscular and skeletal systems are often grouped under one name: the musculoskeletal system. In addition to allowing us to move, the musculoskeletal system provides form, support, stability and protection to the human body. The role of the bones may extend beyond all these mechanical roles; for example the bone marrow is the location of the formation of red blood cells.

Muscle movement is controlled by the nervous system and muscles respond to **stimuli** by **contracting**. Muscles and bones need a rich supply of blood to provide the oxygen needed and remove the carbon dioxide resulting from cellular respiration in the muscles (see Chapter 5).



■ **Figure 7.8** Diagram showing how muscles and bones are attached

HOW DO WE MOVE?

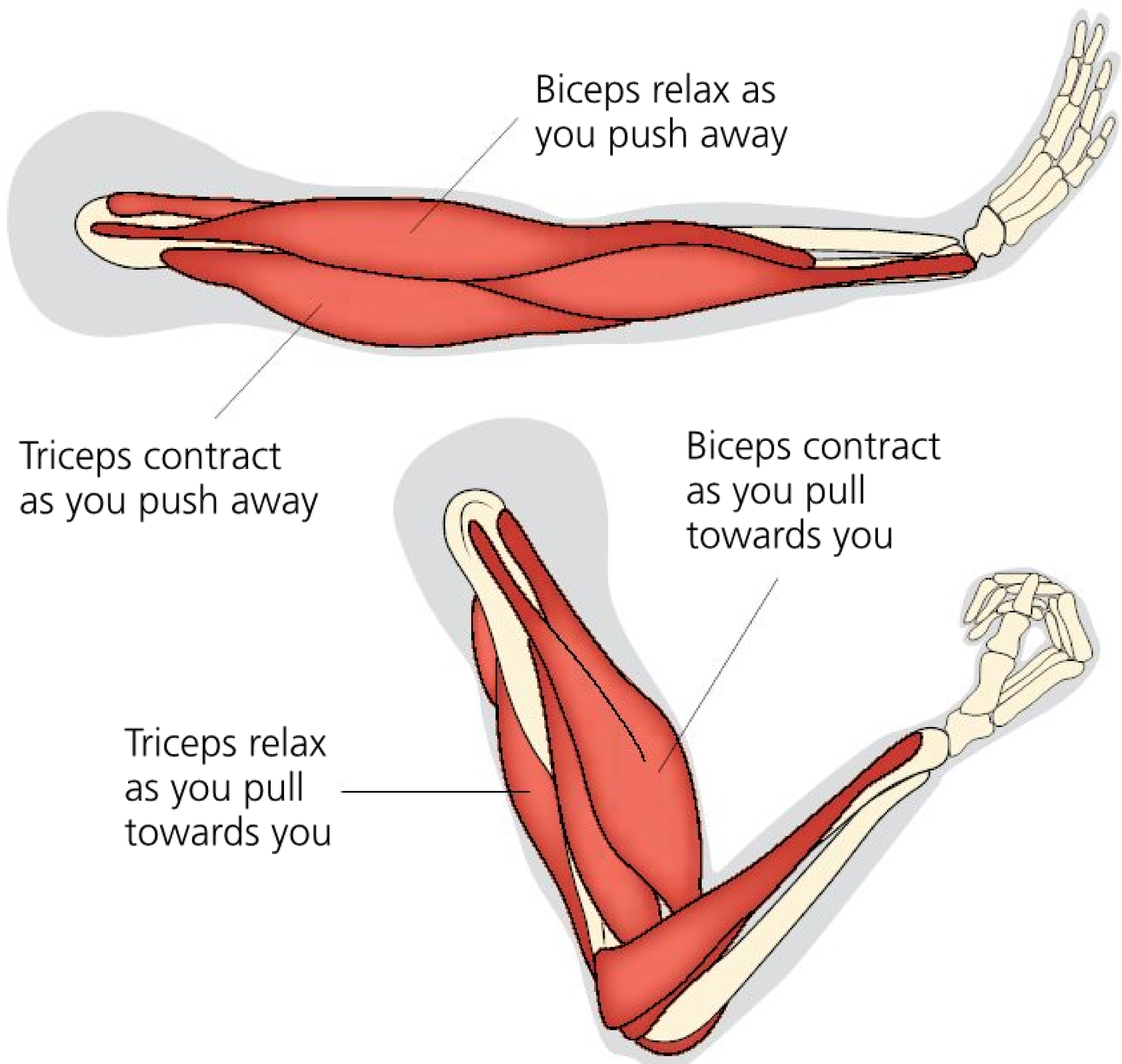
SEE–THINK–WONDER

What do you **see** when your arm is at rest? Which muscle contracts when the arm is in the resting position? What happens to the other muscle at the same time?

Now observe the muscles again but this time when the arm is lifted. What happens to the biceps and the triceps now?

What do you **think** would happen if these muscles contracted or relaxed at the same time?

What do your observations make you **wonder** about the way the muscles work in your arm?



■ **Figure 7.9** Bending of the arm is caused by antagonistic muscles

There are two types of muscles in the upper part of the arm: the triceps and the biceps (see Figure 7.9). In each limb of the body, pairs of muscles like these allow the movement of the limb. Pairs of muscles that act opposite to each other like the ones shown are called **antagonistic** muscles. Bending of limbs is controlled by these types of muscles. There are many other types of muscles that assist these muscles for better control of the direction of the movement.

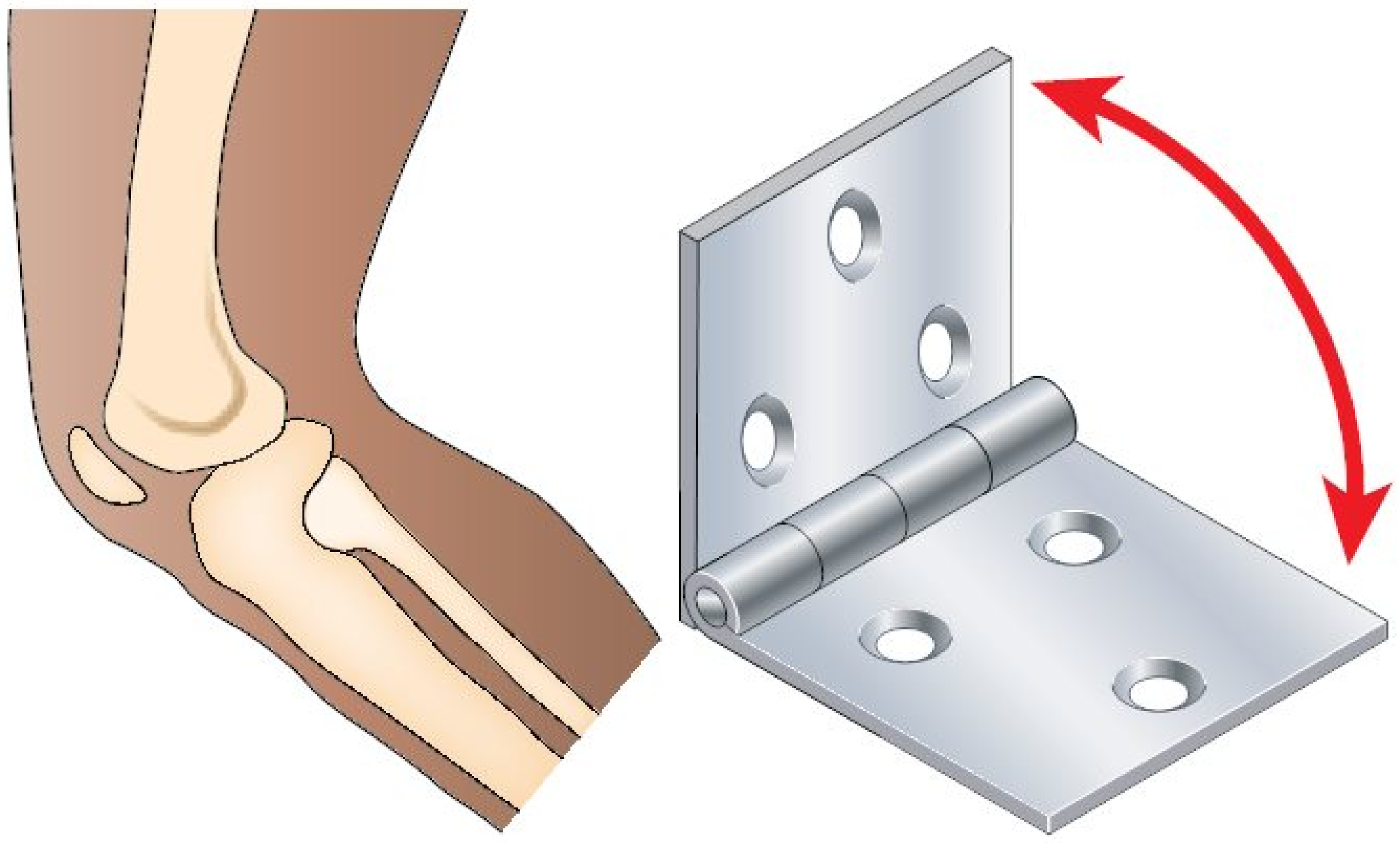
Limbs are made to move through muscle contraction and usually this results in their length decreasing; this type of contraction is called **isotonic contraction**. There are times when muscles need to do work and contract without changing length and this is called an **isometric contraction**.

DISCUSS

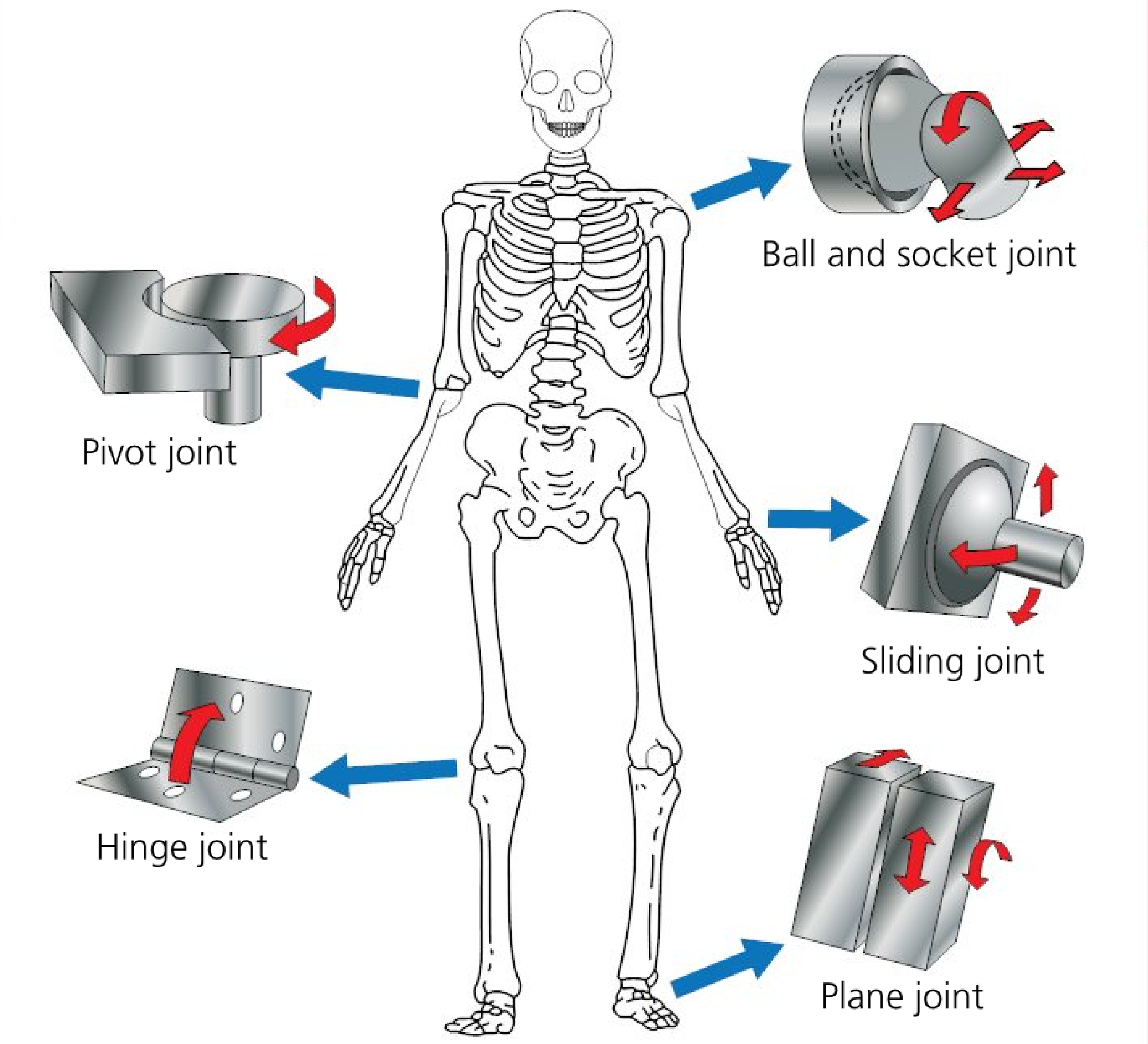
Can you think of examples where isotonic and isometric muscle contractions happen? **Discuss** in groups and have a volunteer to **demonstrate** these contractions to **justify** your choice.

WHAT MAKES YOU SAY THAT?

Look at the diagram in Figure 7.10. How is the knee joint similar to a door hinge? In which way are they different? What makes you say that?



■ **Figure 7.10** Comparing the knee joint to a door hinge

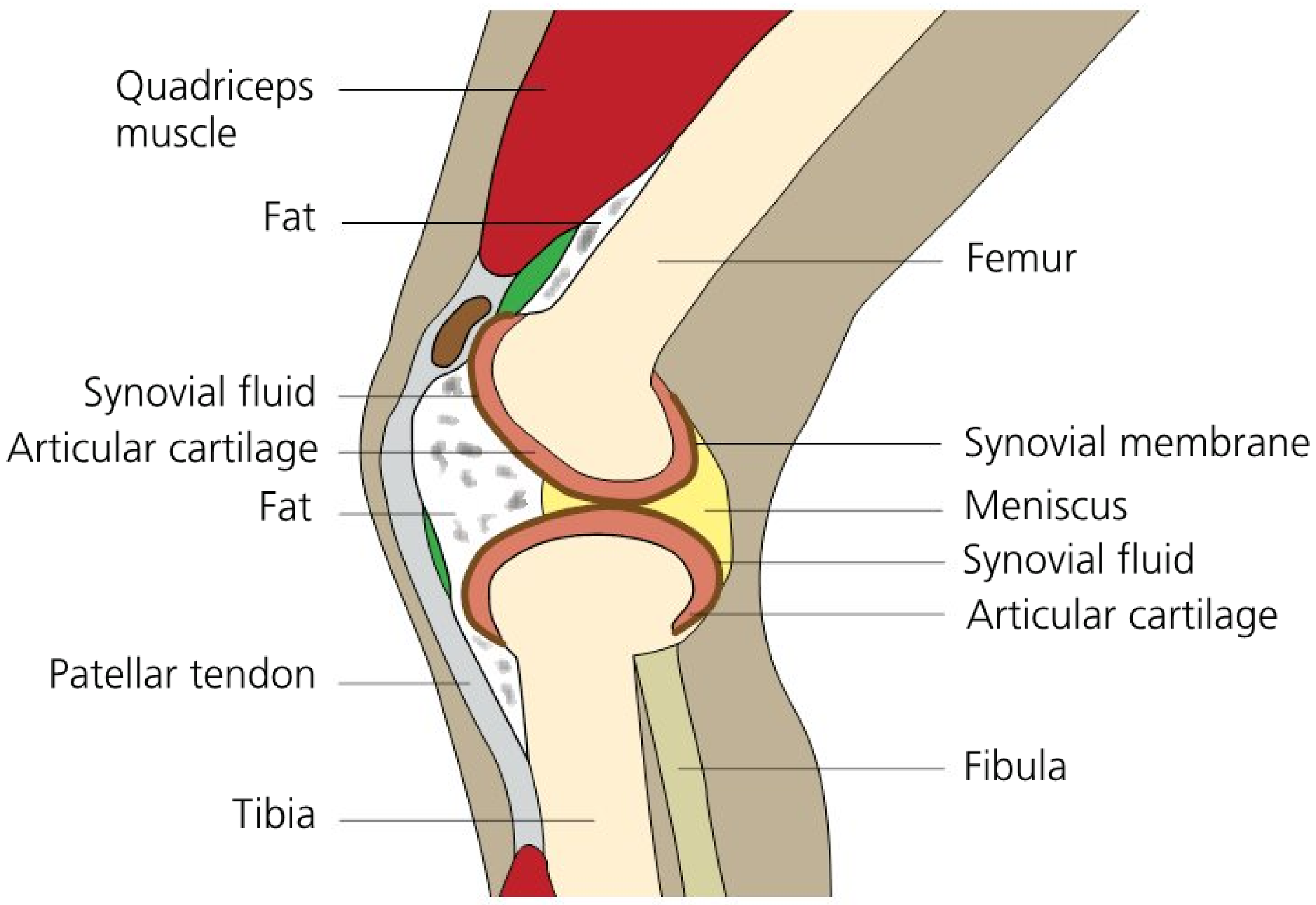


■ **Figure 7.12** Types of joints in the human body

WHAT IS THE ROLE OF JOINTS IN MOVEMENT?

Joints are the articulation and the meeting point of bones. Each bone ends in a softer structure called **cartilage** and the space between the cartilage of each bone contains a special lubricant fluid called **synovial fluid** which allows movement without friction (see Figure 7.11).

There are many types of joints in the human body and they determine the nature of the movement in that part (see Figure 7.12). For example, the elbow has two types of joints, the hinge joint and the pivot joint. Can you think of the reason for that?



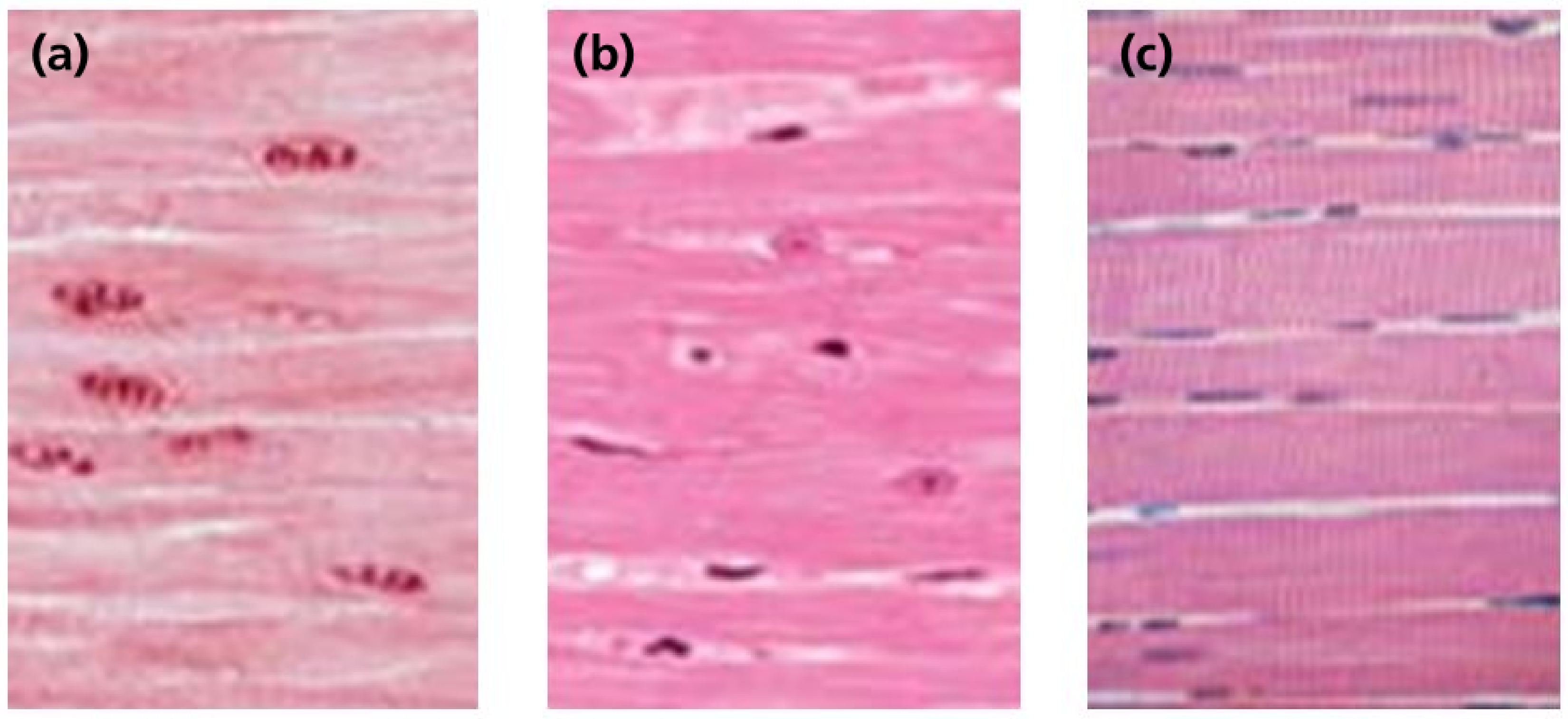
■ **Figure 7.11** Structure of the knee joint

EXTENSION

Find out more about what causes knee and elbow problems in some people. Search: knee, elbow, diseases, causes. What makes some individuals more at risk of developing these diseases? What measures can we take to prevent these issues?

ZOOM INTO THE MUSCLE!

Muscles attached to the skeleton are only one type of muscle in the body; there are other types of muscle that are completely independent from the skeleton, as you will see in the next activity. So far we have looked at how muscles and bones work together to allow movement. But what happens at the cellular and microscopic level? What structures allow a muscle to actually contract and change length?



■ **Figure 7.13** The three types of muscle as seen under the light microscope

ACTIVITY: Sort your body's muscles!

ATL

- Communication skills: Organize and depict information logically
- Information literacy skills: Present information in a variety of formats and platforms

There are around 650 different muscles in the body performing different functions. They are grouped into three categories based on their tissue and cell structure: skeletal, cardiac and smooth muscles.

1 **In pairs or individually, identify which diagram represents which type of muscle then match with the example organ and the definition given in Table 7.3**

2 **Figure 7.13 shows light microscope images of the three types of muscles shown in the table. State which type of muscle is shown in each image (a, b and c).**

3 **Outline the differences that you see in these three types of muscle. What similarities do they all have?**

4 **Summarize all the information you learnt from this activity in an A4 poster or an infographic that you will display in your class.**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

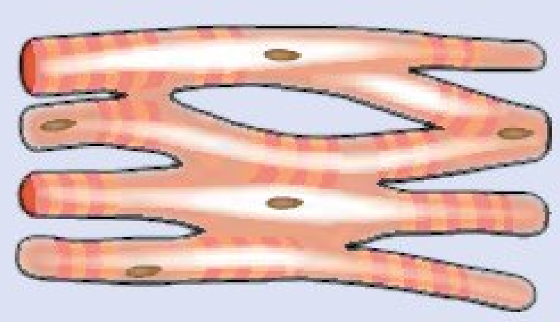
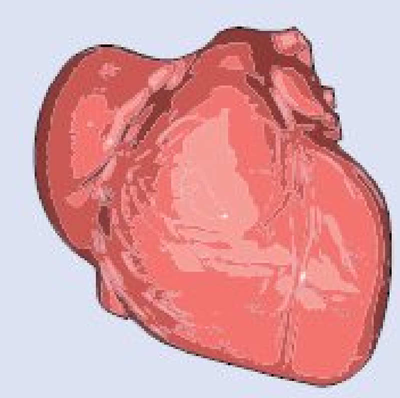
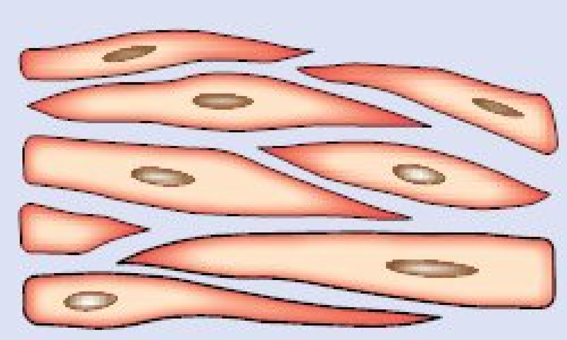
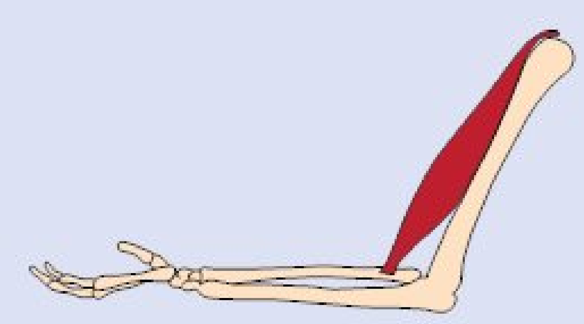
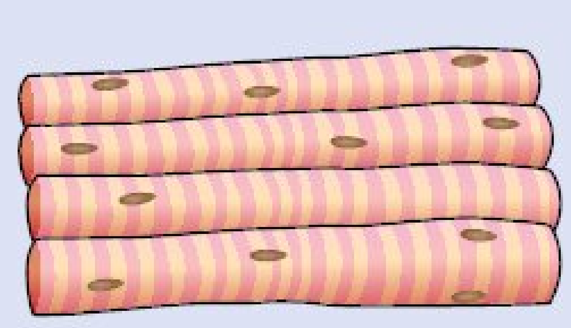
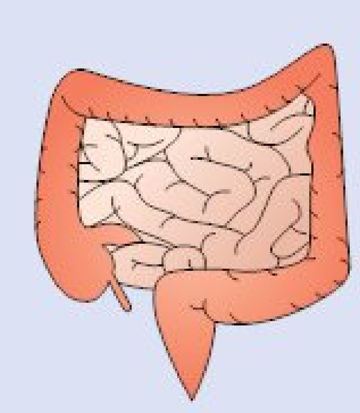
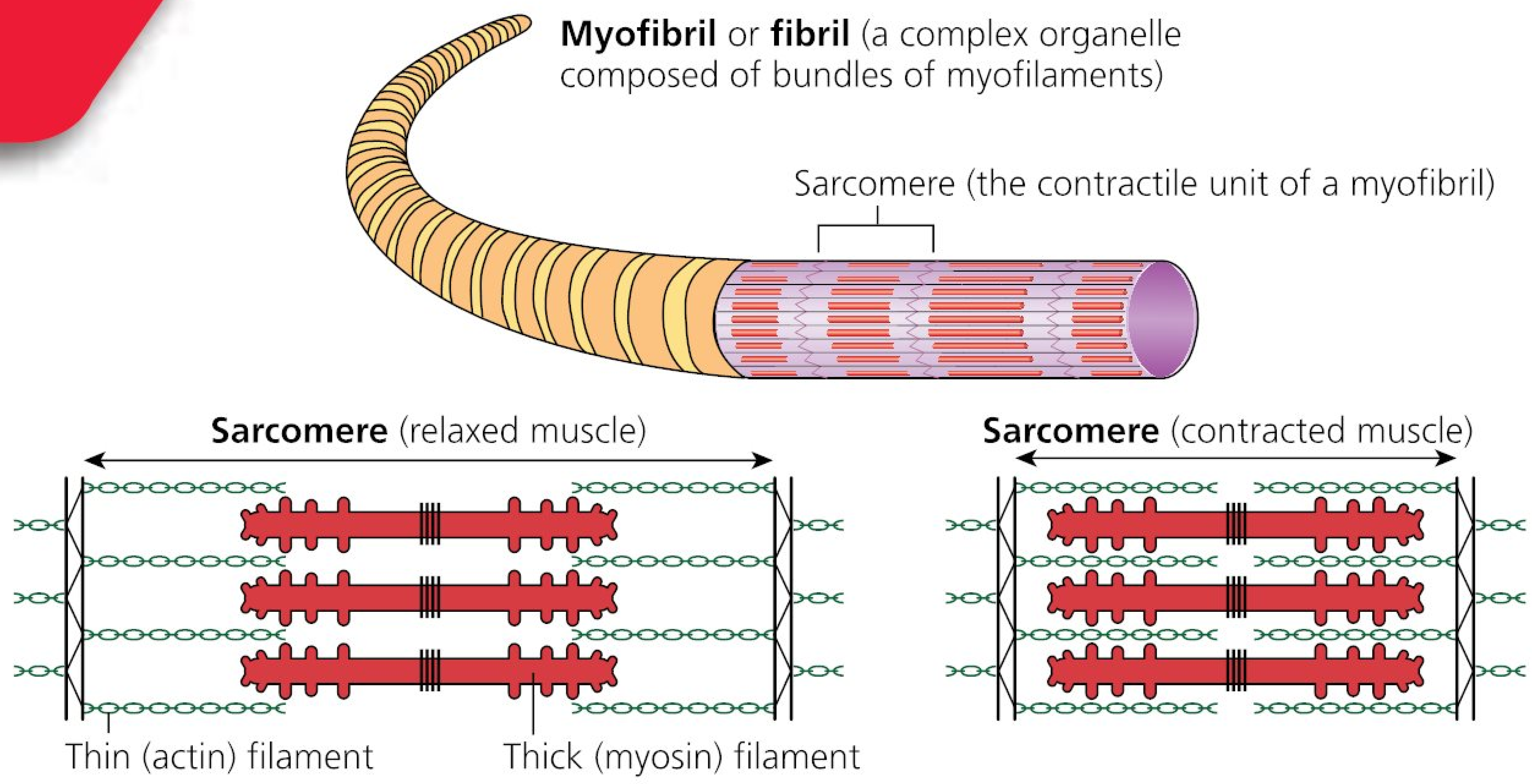
Type of muscle tissue	Diagram of muscle tissue	Example organ	Definition
skeletal (or striped) muscle			Made up of stripy large cells, with many nuclei inside. Responsible for conscious movement of parts of the skeleton.
cardiac muscle			Made up of stripy cells that branch and connect with each other. It works involuntarily and does not stop or fatigue throughout life.
smooth muscle			Made up of large, spindle-shaped cells with one nucleus in each. Found in the internal walls of hollow organs. It works involuntarily.

Table 7.3 Types of muscles in the human body

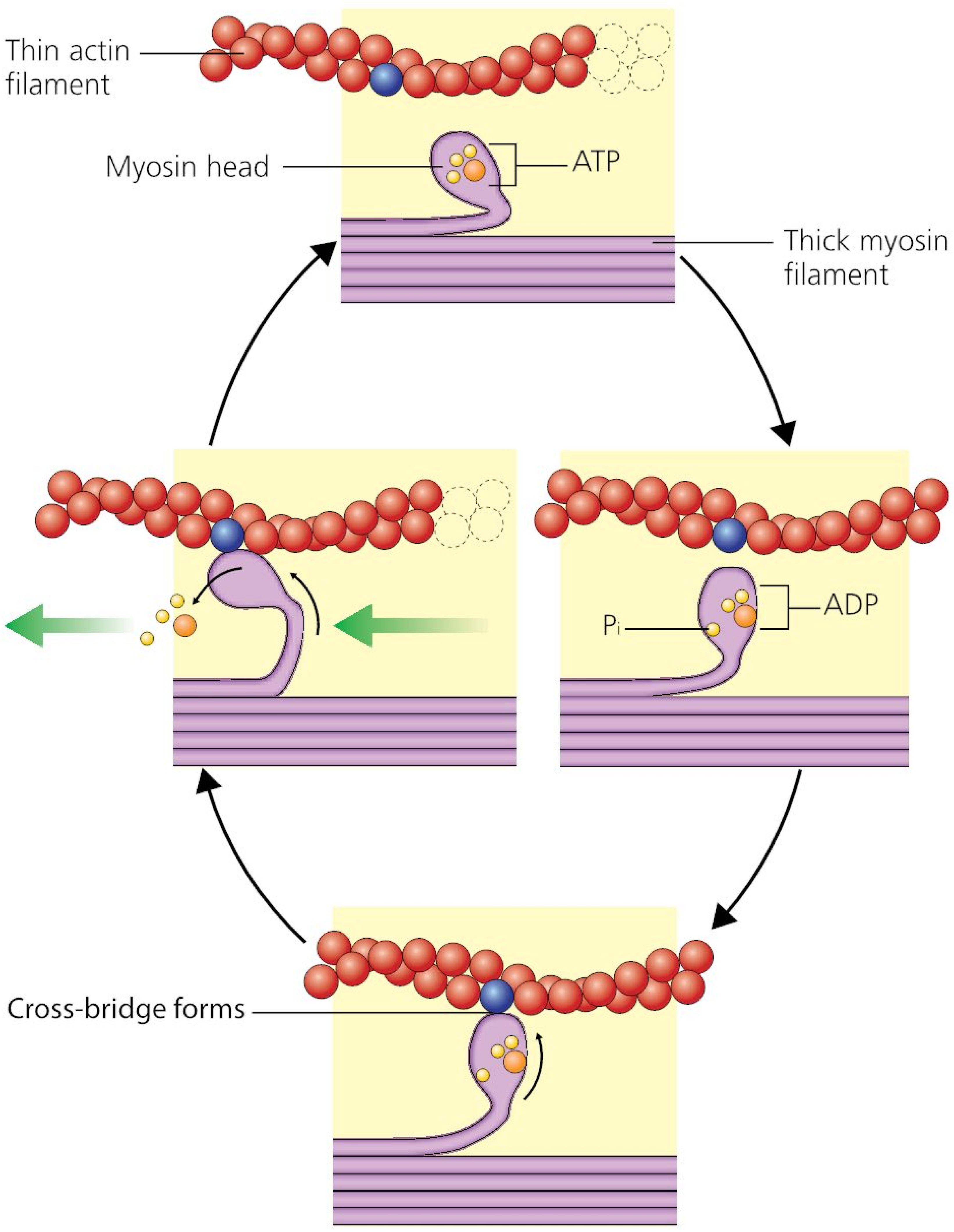
In this section we will focus on the skeletal muscle. The skeletal muscle tissue is made up of muscle cells organized into bundles called **fibres** (see Figure 7.14). A skeletal muscle cell is very long and, unlike most cells, may contain more than one nucleus. Each fibre has smaller bundles called **myofibrils** which are in turn composed of **myofilaments** arranged in **sarcomeres**. The overlapping of myofilaments creates the banding seen in the skeletal muscle tissue. Each sarcomere forms a 'contractile unit' – a region of muscle tissue capable of contraction – and is made up of thick central protein structures called **myosin** and thin proteins called **actin** (Figure 7.17).

Myosin filaments end in heads that link to the actin filament forming **cross bridges** and causing them to slide against each other. This can best be explained by the sliding filament model (Figure 7.16). This action requires calcium ions (Ca^{2+}) and energy in the form of ATP. Muscle cells contain large numbers of mitochondria. Can you think of a reason based on what you learnt in Chapter 5?

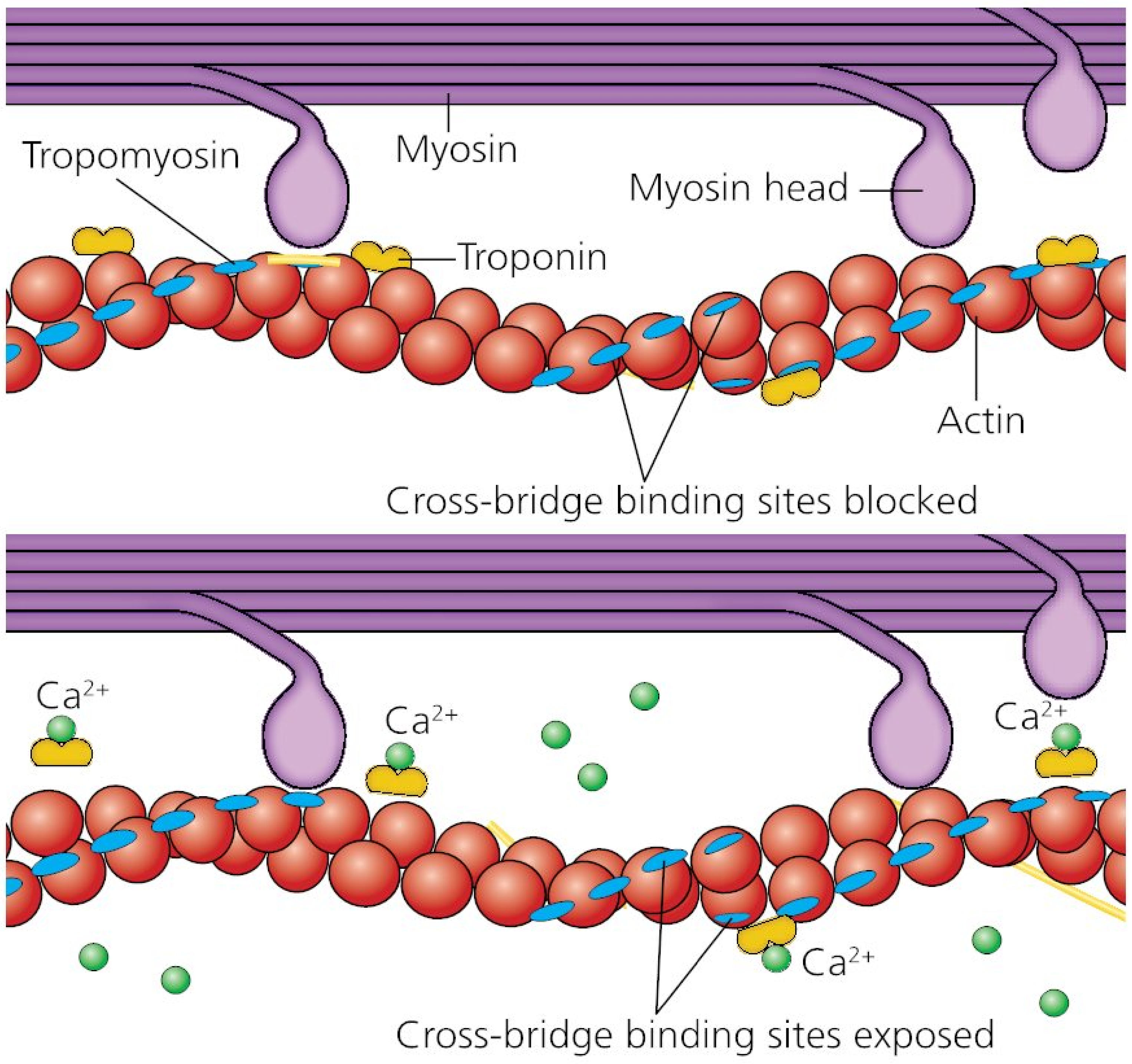
■ **Figure 7.14** Skeletal muscle structure



■ **Figure 7.15** Structure of the skeletal muscle fibre



■ **Figure 7.16** The sliding filament process



■ **Figure 7.17** A deeper look into the mechanics of muscle contraction in a sarcomere

How can the understanding and application of mechanics improve lives?

We have seen in this chapter how the musculoskeletal system enables us to perform a huge variety of functions. From a physical point of view, it is a system of **levers**. You may recall from *MYP Sciences by Concept 3:* Chapter 1 that levers use forces acting at a distance from a **fulcrum** to achieve **mechanical advantage** – whether by operating as a force magnifier or as a distance magnifier. As we have already seen, the human arm is one lever system.

ACTIVITY: Reviewing levers

ATL

- Critical-thinking skills: Practise observing carefully; Recognize and evaluate propositions

Look at the different lever types in Figure 7.18.

Discuss with your partner why you might use each kind of lever. **Summarize** the advantages and disadvantages of each. **Suggest** other possible machines or situations in which you might use each of the classes of lever.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

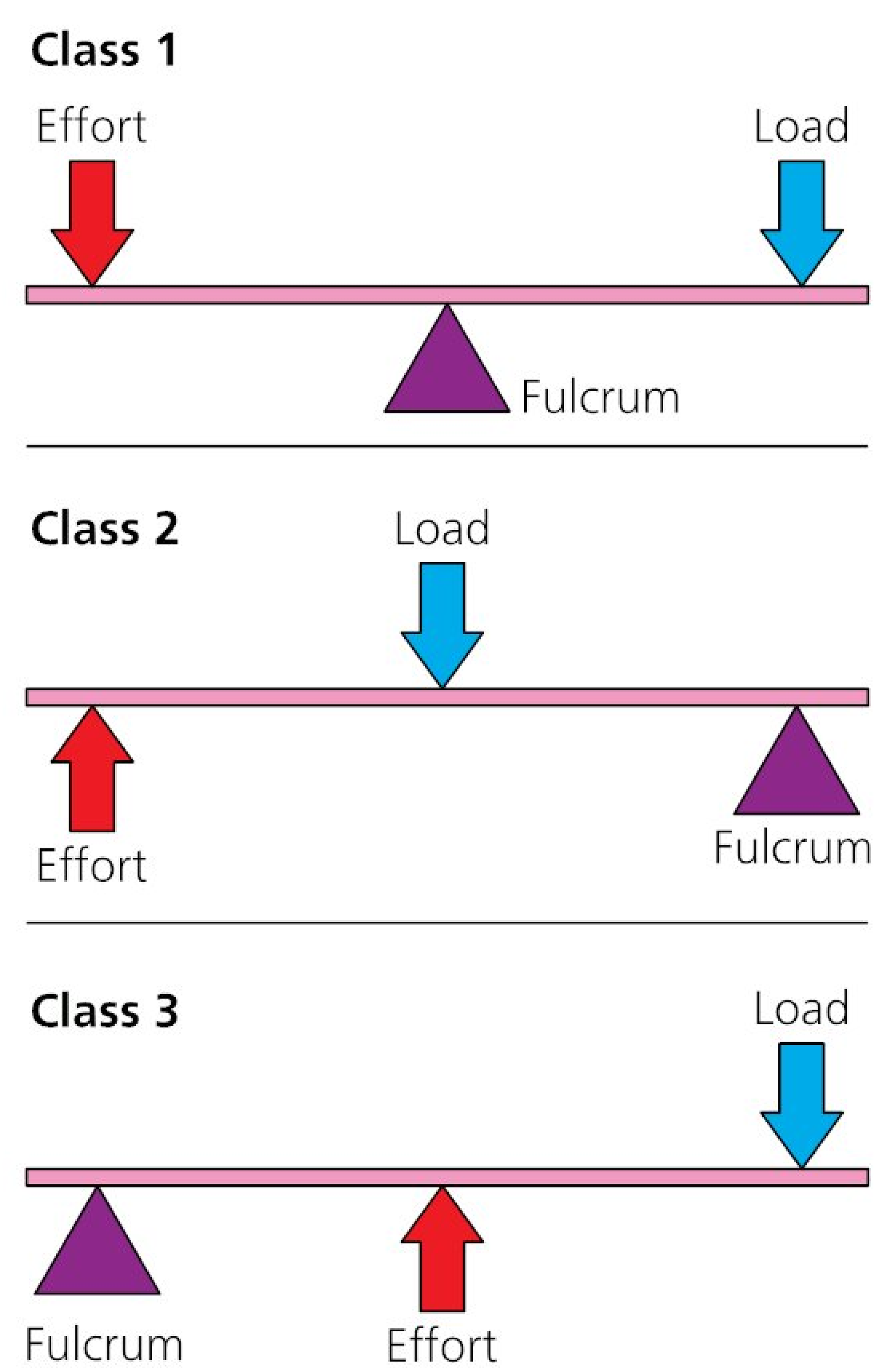


Figure 7.18 Lever types

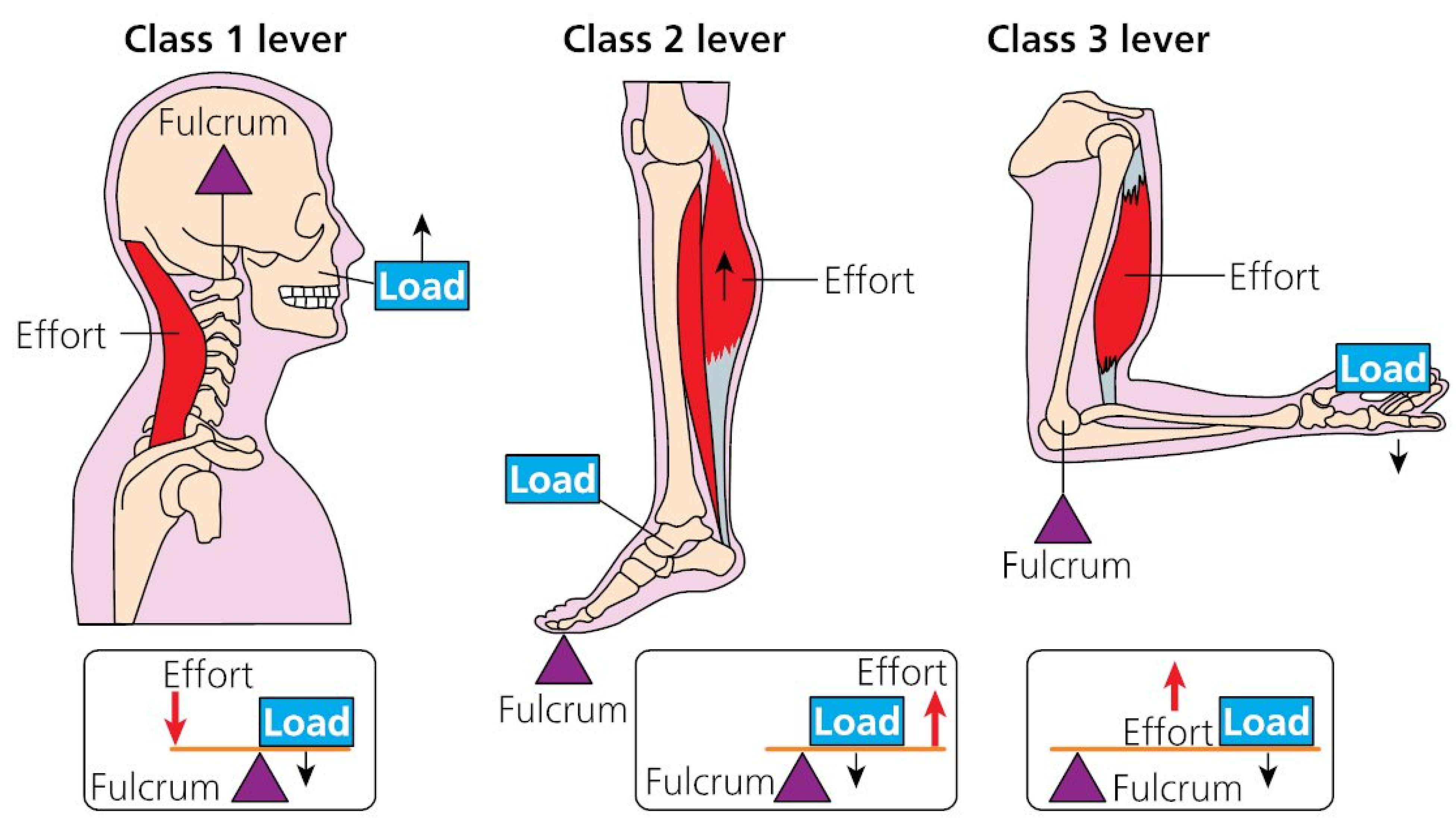


Figure 7.19 Levers in the human body

ACTIVITY: How much can you lift?

ATL

- Creative-thinking skills: Apply existing knowledge to generate new ideas, products or processes
- Critical-thinking skills: Interpret data

When designing machines, we always look for the most efficient way of doing work. So how efficient is the human machine? In this experiment, you will use a part of the human machine (your arm muscles!) to **investigate** factors affecting how much weight you can lift with your arm bent. Use the MYP *Sciences Inquiry Cycle* from Chapter 1 to **design** an experiment to answer the question. Think carefully about how you will control and manipulate your variables.

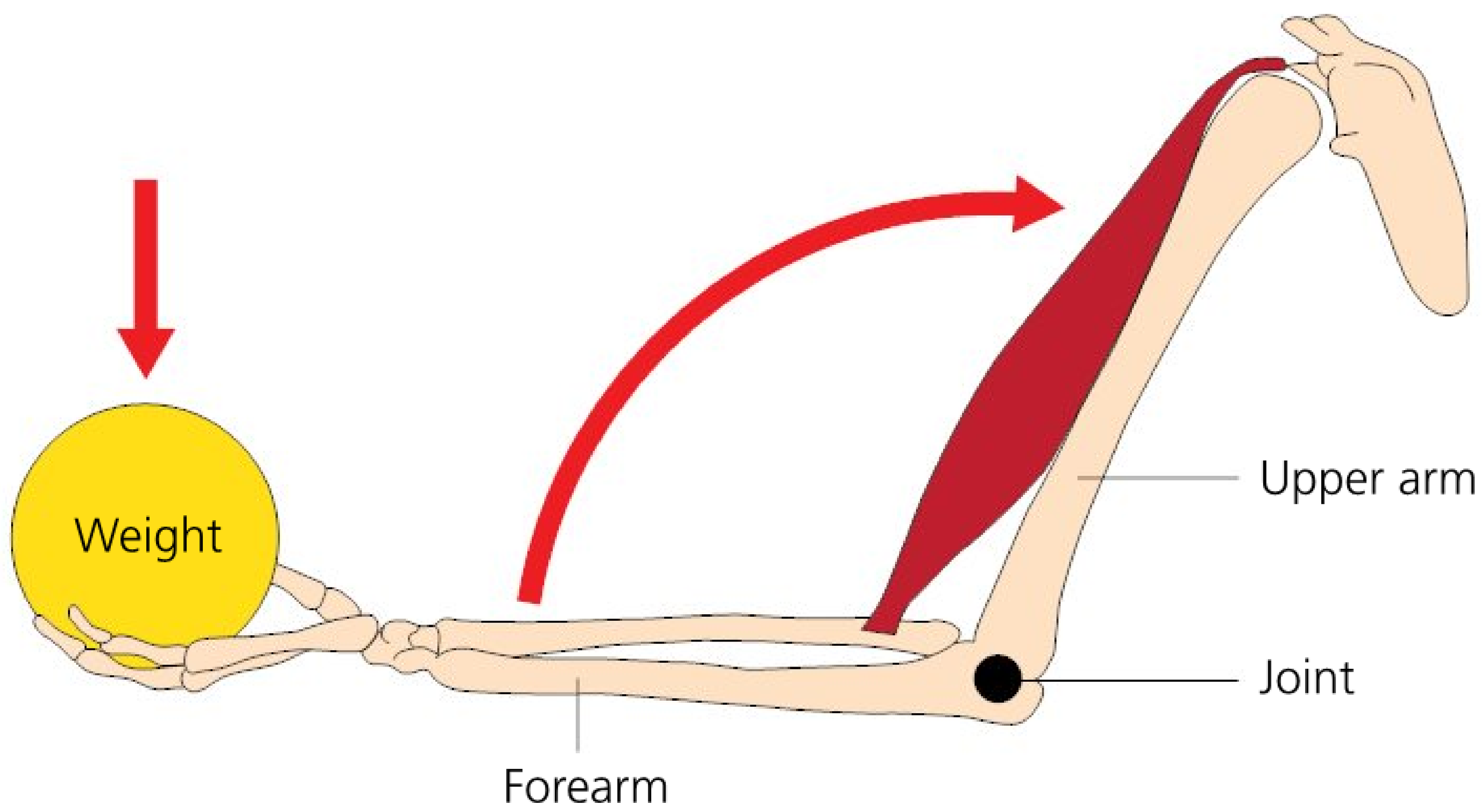


Figure 7.20 The human arm is a lever

Assessment opportunities

- This activity can be assessed using Criterion B: Inquiring and designing and Criterion C: Processing and evaluating.

Links to: Design

Ergonomics is the art and technique of designing objects to work well with the human body. It is just one of the factors that contribute to the design of any object for use by humans. What other factors must be important when designing such objects?

Figure 7.21 An ergonomic design

Links to: Physical and health education (PHE)

In PHE you study how the musculoskeletal system works and its impact on health, fitness and performance in physical activities. The field of study that focuses on this is called sports science and is an area where biology and physics work closely together.

Links to: Design

Making a robot arm

Ask your design teacher to allow you to **design** and **construct** a robot machine to **demonstrate** the way that the human arm works. Your machine can be as simple or as complicated as you wish. Research ideas online using YouTube or image search: **model robot arm**.

Figure 7.22 LEGO® is great for model robotics.

Here are some ideas for materials you might use:

- For a simple robot arm: stiff card, paper fasteners, elastic bands, sticky tape.
- For a more complex arm: plastic construction toy, screw-drives, electric motors with worm gear.

MEET A SCIENTIST: STEPHEN HAWKING

British physicist Stephen Hawking was one of the most famous scientists of our times. His work in the field of cosmology changed the way that scientists understood the relationship between the big picture of the Universe and the infinitesimal scales of quantum mechanics. While Hawking's work was grounded in mathematical rigour, he also recognized the importance of speculation and imagination.

While an undergraduate student at Oxford University in the 1960s, Hawking began to notice difficulties in controlling his movements. He was later diagnosed as having amyotrophic lateral sclerosis, a degenerative disease that results in the loss of muscle control. This was a very difficult time for him, especially when in 1963 he was given a life expectancy of only two more years. Thankfully that original prognosis was soon outlived and Hawking continued his brilliant work until 2018. Hawking used a wheelchair and a computerized speech synthesis system that was controlled by a sensor that detected movement of his cheek. He continued to lecture, to publish papers in physics and to write popular science books, including his best-selling 1988 book *A Brief History of Time*. With the aid of technology, Hawking was one of the most significant **thinkers** in modern science.

■ **Figure 7.23** Stephen Hawking

ACTIVITY: Replacing the human body

ATL

- Information literacy skills: Access information to be informed and inform others
- Creative-thinking skills: Design improvements to existing machines; Apply existing knowledge to generate new ideas, products

In Chapter 4 we explored how new materials and understanding of structural forces have enabled para-athletes to record ever greater achievements in sporting competition. What if the prosthetic limbs were also robotic?

Individually find out about the emerging technology of **neuroprosthetic surgery**. You can find a useful video through searching: **paralysed man feed himself new technology Guardian video**.

Imagine you are an engineer who wishes to start a new company researching, experimenting with and ultimately manufacturing prosthetic robot devices.

Choose one example of a limb that might be replaced in this way. **Describe** the problem to be solved and **explain** how the limb can be replaced, with reference to the science you have learnt in this chapter. **Discuss** some of the issues that you expect to face as an engineer wishing to start a new company and **evaluate** how they might impact on your plans. Be sure to **apply** scientific terms you have used clearly and precisely and to **document** sources.

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

How are force and motion related?

WHAT MAKES YOU SAY THAT?

Describe what happens if the rower in Figure 7.24b stops rowing and raises her oars out of the water? What makes you say that?

What forces cause the rowing boat to stop eventually?

APPLYING SOME FORCE

Levers use force to produce a turning motion or moment. Force applied to matter can also produce a change in shape, or deformation. Of course, the motion that Olympic sprinters and other athletes achieve is also a consequence of force. In the case of sprinters, the rapid contraction and relaxation of their leg muscles generates a resultant force that pushes their feet against the ground. This *action* produces a *reaction* that pushes back against the foot and so propels the runner upwards and forwards (Figure 7.24a).

Similarly, the rower in Figure 7.24b is applying force (via the oar) to the water, and the water is pushing back with a reaction that is equal in size and in the opposite direction. This propels the rower and boat through the water.

You may know or recall from *MYP Sciences by Concept 2:* Chapter 1 that we conceptualize forces in this way following the thinking of Italian philosopher Galileo Galilei (1564–1642) and later Isaac Newton in Britain (1643–1727). We can understand forces as action–reaction pairs using **Newton's third law of motion**, which can be stated:

For every action there is an equal and opposite reaction.

Similarly in Chapter 2 we saw how force fields act on matter at a distance, producing action–reaction pairs.

Once the rower stops rowing, the boat will glide to a halt in the water. We are familiar with this kind of behaviour from all objects from the very first experiments we carry out as children. In fact, it seems so evident that objects will eventually slow down and stop that for most of recorded history people believed that it was somehow in the 'nature' of matter to do so. This was certainly the view of Aristotle, the Greek classical thinker (384–322 BCE). Again it was Galileo who noted that this was *not* because matter tended to stop of its own accord, or even when it has reached its 'rightful place' in the Universe (as Aristotle argued). Rather the effect was due to the action of other forces.

On Earth, there is *always* a force slowing things down, whether friction with the ground (or water) or just with the air (air resistance). In space, however, there are fewer such forces (although space *is* full of force fields, as we have seen and will explore further in Chapter 10). In the absence of slowing forces, objects will continue to move forever (Figure 7.25).

This tendency of matter to remain in whatever state of motion it has until a force is applied is called inertia and Newton conceptualized this in his **first law of motion**:

An object at rest will remain at rest unless acted on by an unbalanced force. An object in motion continues in motion with the same speed and in the same direction unless acted on by an unbalanced force.

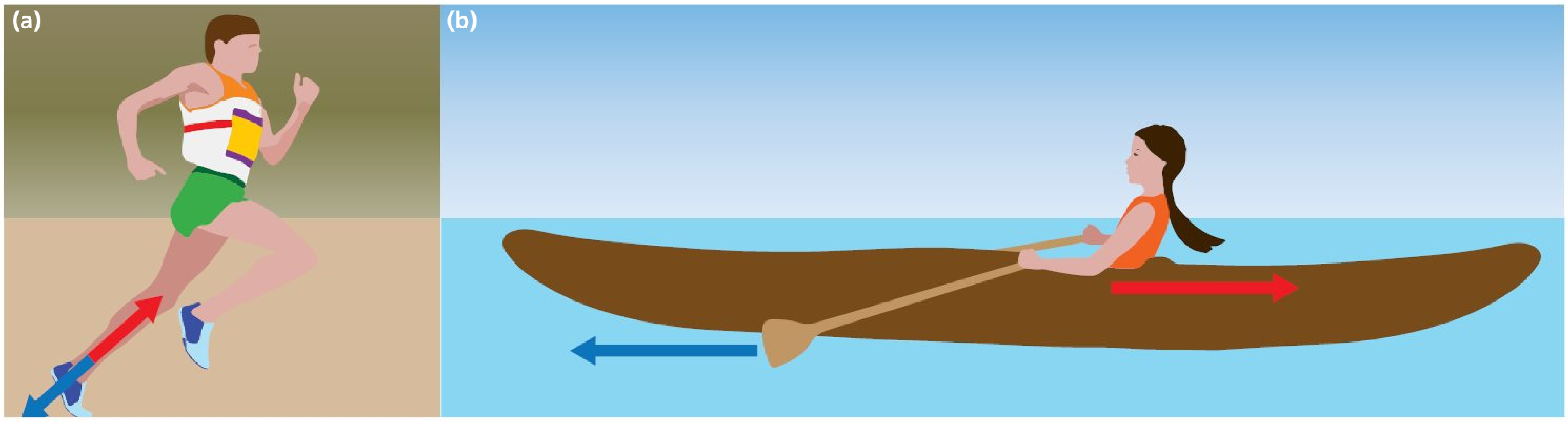


Figure 7.24 Forces being applied: (a) a sprinter's foot, (b) a rowing boat. Blue arrows show the *action*, such as the force applied by the athlete. Red arrows show the *reaction* to this from the ground or from the water.

EXTENSION

Newton conceptualized the inertial properties of mass using the concept of momentum, where

momentum = mass × velocity

$$p = mv$$

(Momentum is given the SI unit kg m s^{-1}.)

The law of conservation of momentum helps to link the concepts of inertia, action and reaction. Find out more in *MYP Physics by Concept 4&5:* Chapter 5.

Hint

The term 'at rest' is used to mean 'not moving', so whenever you read this you can assume the velocity of the object is zero.

The change in motion that a force causes is called acceleration, as we have already seen. This could be a change in speed or a change in direction or both at the same time. **Newton's second law of motion** links force, mass and acceleration:

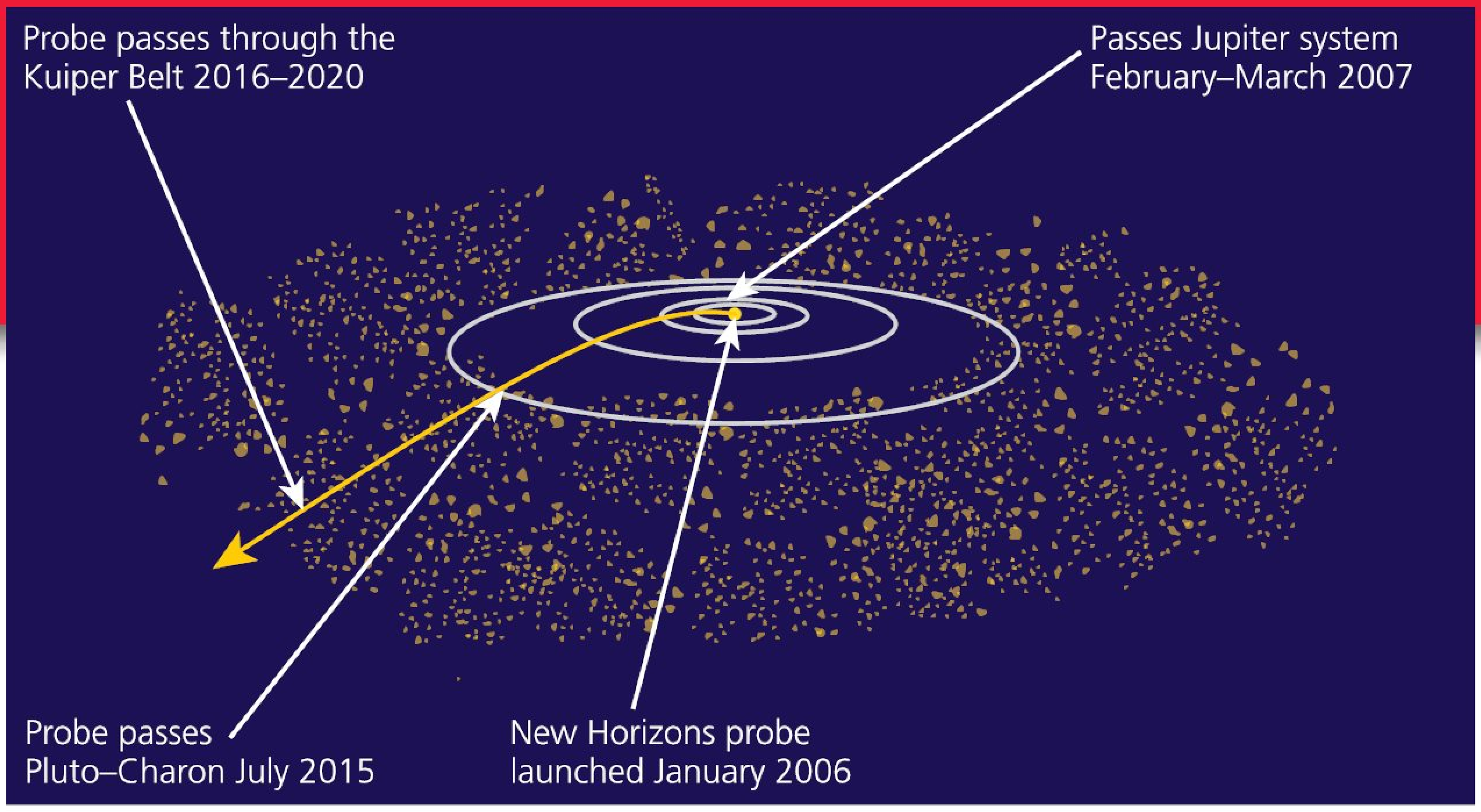
When force acts on mass, acceleration may be produced. The acceleration produced is in proportion to the force applied to the mass and in its direction.

The second law is summarized in this way:

force = mass × acceleration

$$F = ma$$

where force is measured in newtons (N), mass in kg and acceleration in m s^{-2}.



■ **Figure 7.25** Trajectory of NASA 'New Horizons' space probe. Launched in 2006, the probe passed the orbit of Pluto in 2015 and is now continuing into deep space.

Worked example

The rower and boat in Figure 7.24b have a combined mass of 100 kg. The boat begins at rest and then the rower applies a force of 50 N to each of the oars.

Describe the effect of these forces on the motion of the boat.

Solution

The force applied to the oars is applied in turn to the water as an action. The water pushes back with a reaction that is equal and opposite, i.e. –50 × 2 = –100 N. This causes the boat to accelerate backwards.

Calculate the size of the acceleration produced on the boat.

Solution

Rearranging Newton's second law we have

$$a = \frac{f}{m}$$

so

$$a = \frac{-100}{100}$$

$$a = -1.00\ \text{m s}^{-2}$$

In reality, the boat and rower achieve a much lower acceleration. **Explain** why this might be.

Solution

The calculated value tells us the acceleration that would be achieved if the boat had no other forces acting on it. In reality, the water applies a 'drag' force against the motion and, to a much lesser extent, so does the air. The resultant of these forces together subtracts from the accelerating force of the rower and so the net acceleration is less than the calculated value.

ACTIVITY: Measuring acceleration

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument; Evaluate evidence and arguments

What affects the acceleration of an object?

Aim

In this investigation we will attempt to **measure** the mass of a trolley by measuring its acceleration. You will use Newton's second law to **measure** the acceleration of a force on a rolling trolley and so find the mass of the trolley (without weighing it!).

Equipment

- **A dynamics trolley or other rolling object**
- **A long ramp, length 1–2 m**
- **A pulley**
- **Some string**
- **Ten masses, 100 g or so each**
- **Ticker-tape timer, photo-optical timing gates or ultrasonic distance measuring device**

Variables

Controlled variable: mass of the whole system, M

Changed (independent) variable: accelerating force, f

Measured (dependent) variable: acceleration of trolley, a

General method

1. **Set up the ramp and trolley as shown in Figure 7.26.**
2. **If the pulley does not have a suitable clamp attached to it, fix it firmly in place with a lab stand and clamp.**
3. **Begin by piling all the masses on the trolley, so that only the mass hanger is 'pulling' the trolley.**
4. **Release the trolley to roll along the plane and measure the acceleration using one of the methods given opposite.**
5. **Now take a mass from the trolley and transfer it to the mass hanger. Release again and measure acceleration.**

Repeat the experiment until all the masses have been used.

Hypothesis

1. **Write a hypothesis about the motion of the trolley as the mass is transferred to the hanger.**
2. **Explain your prediction with reference to Newton's second law.**

Hint

What is providing the accelerating force on the trolley? What is the total mass of the whole system that is being accelerated?

Measuring the acceleration

There are different ways to measure the acceleration, depending on the equipment available.

After reading the method and analysis for your chosen acceleration technique, **design** a data table to record your 'raw' or unprocessed data from the experiment.

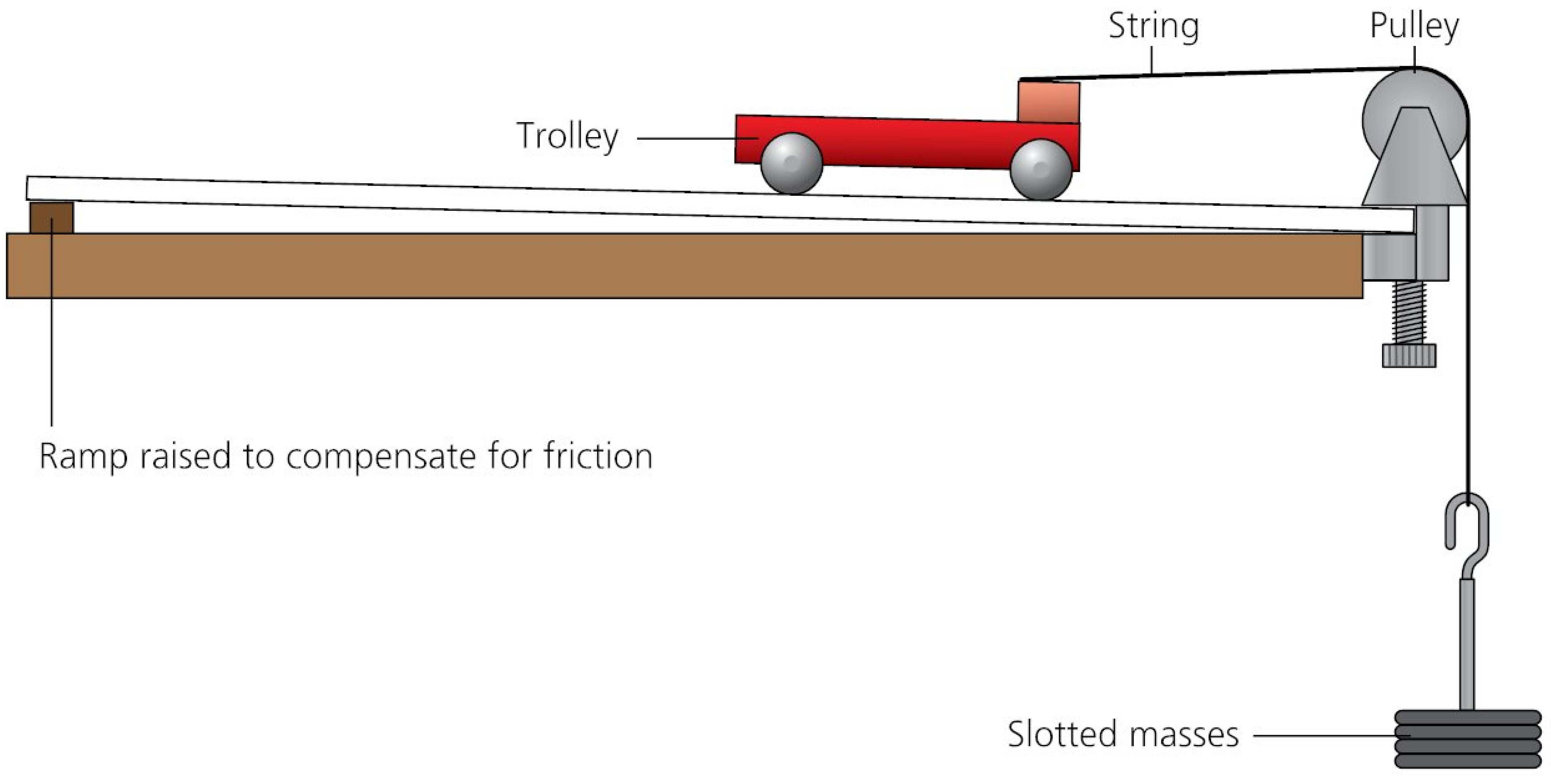


Figure 7.26 Experiment set-up for plane and trolley

Method 1: Using the ticker-tape timer

A ticker-tape timer has a small needle that vibrates at a known rate. The needle makes a mark on a long, thin piece of paper tape that runs through the timer. This gives a 'trail' of marks whose distance apart can be used to measure velocity, and so acceleration for the trolley.

To use the timer, fix one end of the tape to the trolley and pass the other end through the timer machine. When you are ready to release the trolley, turn on the ticker-tape timer first, then go!

Data analysis using Method 1

You can use the tapes to produce a distance–time graph. Simply cut the tape for each 'run' of a different mass every 5–10 dots or so. Place them side by side in order as shown in Figure 7.27.

You can then measure from the tapes to derive the initial and final velocity of your trolley, and so the acceleration of the trolley, as shown on the diagram.

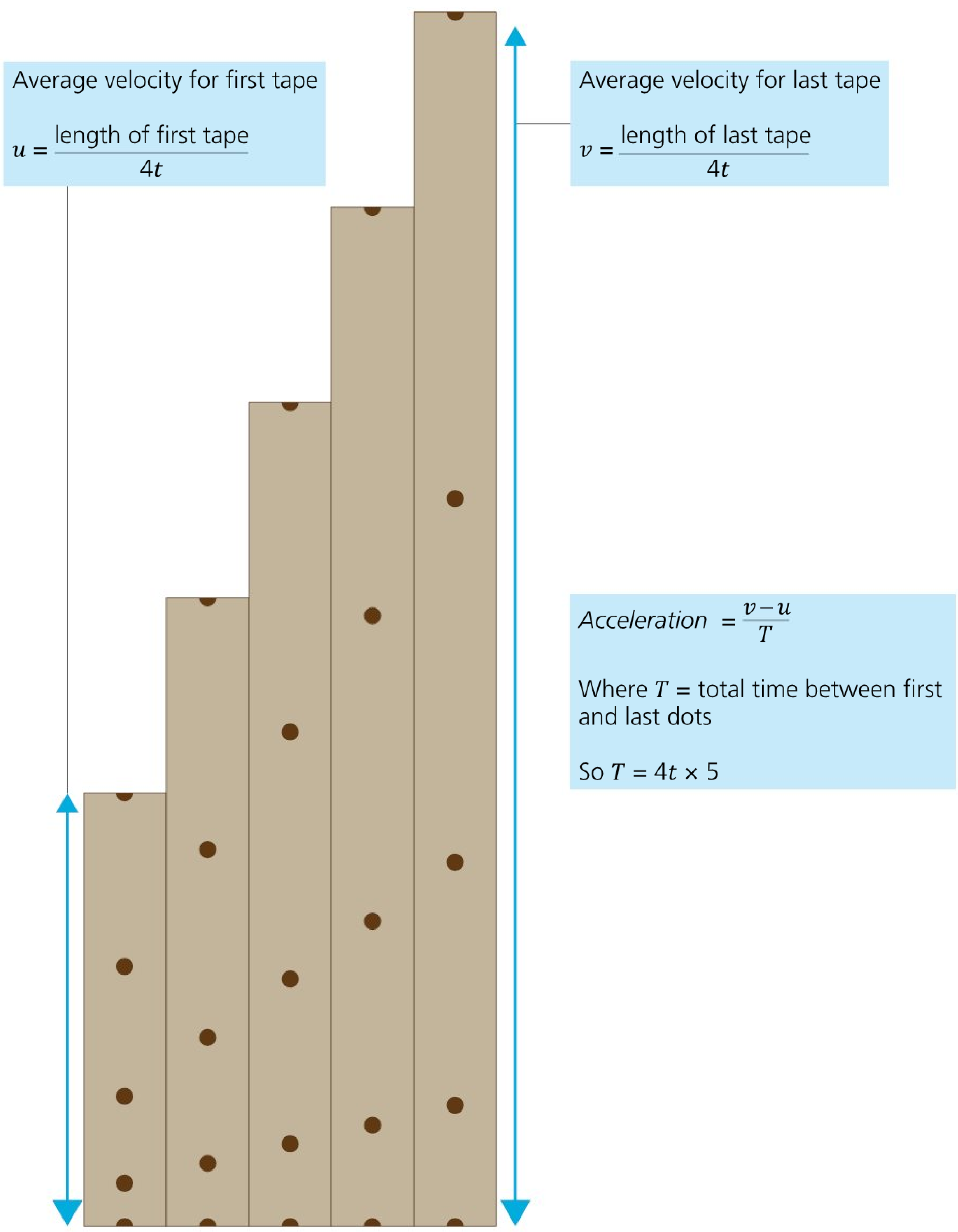
Method 2: Using an ultrasonic distance measurer

An ultrasonic distance measurer emits an audible 'click' which is reflected back from an object and picked up at the receiver (which is usually just a directional microphone built into the unit). The travel time for the click and its **reflection** is used to measure the distance to an object. You may need to use a square of card attached to the trolley to reflect the ultrasonic click effectively.

The distance and time are usually read out on a datalogger, or computer software, both as a data table and graphically.

Data analysis using Method 2

The output from the ultrasonic measurer will give you a constant stream of distances over the whole time of the journey. From these you can select points to calculate initial and final velocities, then calculate acceleration as for the ticker-tape timer in Method 1.



■ **Figure 7.27** Ticker tapes arranged to make a distance–time graph

Interpreting data

- **Design** a second data table to present your calculated or 'processed' values.
- What should you plot on a graph in order to get a straight line from your data?
- **Present** your processed data on a graph showing how the independent variable (force on trolley) affected the dependent variable (acceleration of trolley).
- Use your graph to **determine** a value for the mass of the whole system, M.
- From the value of M you have found, use the total mass of the hanger + 100 g masses to **deduce** a value for the mass of the trolley, m.

Conclusion

Compare the motion demonstrated in your results to the motion you predicted earlier. Was your prediction correct?

Now use a balance to find the actual mass of the trolley. **Compare** the value of m you obtained experimentally to your measured value. Were you correct?

Evaluation

- What problems (sources of error) were there with your experiment?
- **Calculate** the percentage error in the experiment by comparing the experimentally measured trolley mass m to the weighed mass of the trolley.
- What evidence was there in the data that these sources of error were significant?

Hint

How straight was your line? Did the line pass through the origin? What other force(s) might be changing as you add mass to the trolley?

- How important (significant) were each of these problems?
- How could you modify the design of your experiment to remove or lessen these problems?

Assessment opportunities

- This activity can be assessed using Criterion C: Processing and evaluating.

To what extent have scientists learnt from nature? Can robots replace humans?

Take action: The robots are coming

ATL

- Communication skills: Give and receive meaningful feedback; Use a variety of speaking techniques to communicate with a variety of audiences; Negotiate ideas and knowledge with peers and teachers; Take effective notes
- Collaboration skills: Help others to succeed; Listen actively to other perspectives and ideas
- Creative-thinking skills: Create novel solutions to authentic problems

- **Work individually or in groups**. In this task, you are engineers who want to start a company designing and building robots that will help humans do things better, or do things that they cannot currently do. In order to raise funds for your company you need to convince your investors that your ideas are technologically possible, that there is a demand for them and that they will make a profit on their investment. You will have to 'pitch' your idea to a panel of investors and your pitch must be no longer than 10 minutes.
- Watch and take active notes on some of these videos online to find out about some of the latest developments in robotics:

  www.youtube.com/watch?v=o5lMJtQOKSY or video search: **Stanford Stickybot**

  www.youtube.com/watch?v=kbaDdg4LA9k or video search: **most advanced robots**

  www.youtube.com/watch?v=sZ_-yb-TN9M or video search: **ten amazing robots that really exist**

- **Identify** a problem that could be solved or made easier using robotics.
- **Sketch** a 'concept design' that shows how you might use robotics to solve this problem. Make sure that you **label** your design to **explain** how you are using the science you have learnt to solve the problem.
- Prepare a pitch for the panel of investors. In your pitch, **discuss** and **evaluate** what implications your design might have in solving the problem. What challenges will you face, both scientific and non-scientific? How do you propose to meet those challenges?
- When you make your pitch, be sure to use scientific terminology clearly and precisely. **Document** any sources you use according to the guidelines set out by your school.
- After receiving your feedback, write an **evaluation** of your own presentation. Include comments about how you would accommodate the feedback you received from your panel of investors!

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

Giving feedback

At the end of each pitch, give feedback as a class. Try to avoid general statements and keep your feedback focused on the actual presentations. What went well? What was most convincing? What was least convincing? What else could each team of engineers have considered? Be sure to keep your feedback constructive: use the rule 'only give feedback that you would yourself find useful'.

SOME REVIEW PROBLEMS TO TRY

1 a **State** the name of the unit responsible for muscular contractions.
  b **State** the name of one chemical element that is needed for muscle contraction.
  c **Describe** the role of ATP in muscle contraction.
  d **Outline** two differences between the skeletal muscle, the smooth muscle and the cardiac muscle.
  e **Describe** the function of the following structures in the human body:
    i joints   ii tendons   iii ligaments.
  f **Describe** how antagonistic muscles work to allow movement in the limbs.
  g The cardiac muscle contains up to 35 per cent mitochondria compared to the skeletal muscle which only contains 1–2 per cent. **Suggest** an **explanation** for such a difference.
  h The diagram in Figure 7.19 (page 177) gives you three examples of structures in the human body that can be compared to levers.
    i **Suggest** which class of levers (1, 2 or 3) is represented by the following musculoskeletal structures: the neck, the foot and the arm.
    ii **Justify** your answers to part (i) by **explaining** how these body structures work as levers (use forces diagrams in your answer).
    iii **Evaluate** the function of these body structures as machines that facilitate our life.

2 Table 7.4 shows data for the 100 m sprint finals at the 1992 Barcelona Olympics.
  a **Discuss** the significance of the times in the 'reaction' column.
  b Choose any five runners from the race. Using a spreadsheet or otherwise, **interpret** the data to **calculate** the speed of the runners at each 20 m interval. **Plot** these data on a speed–time graph.
  c On your graph, **identify** and **label** the part of each runner's race where
    - the speed was the greatest
    - the acceleration was greatest.
  d Use your graph to **calculate** the average acceleration of the runners for the regions where their acceleration was the greatest.
  e **Evaluate** your data and try to **identify** any patterns in the runners' performances. For example,
    - was there a relationship between reaction time and final placement?
    - was there a relationship between the acceleration and the final placement?

Athlete	Reaction	20 m	40 m	60 m	80 m	100 m
Christie (UK)	0.139	2.93	4.74	6.48	8.22	9.96
Fredericks (NAM)	0.138	2.91	4.74	6.50	8.26	10.02
Mitchell (USA)	0.143	2.93	4.76	6.52	8.28	10.04
Surin (CAN)	0.124	2.89	4.72	6.50	8.28	10.09
Burrell (USA)	0.165	2.99	4.82	6.58	8.32	10.10
Adeniken (NGR)	0.183	3.01	4.84	6.58	8.34	10.12
Stewart (JAM)	0.154	2.95	4.78	6.56	8.36	10.22
Ezinwa (NGR)	0.172	2.99	4.84	6.62	8.42	10.26

■ **Table 7.4** 1992 Barcelona Olympics distance and time data (Data source: Mackenzie, B. (2001) *Sprinting*)

Reflection

In this chapter we have **described** the structures that enable the human body to move and meet its needs. We have **outlined** muscle contraction at the cellular level and **described** how the products of respiration are used to enable movement in the muscle. We have **outlined** examples of ways in which scientists have been learning from nature to design machines that can make our lives easier. We have used understanding of Newton's laws to **describe** the relationship between forces and motion and to **calculate** accelerations. We have **discussed** the possibility that robots could replace humans.

Use this table to reflect on your own learning in this chapter						
Questions we asked	Answers we found	Any further questions now?				
Factual						
Conceptual						
Debatable						
Approaches to learning you used in this chapter	Description – what new skills did you learn?	How well did you master the skills?				
		Novice	Learner	Practitioner	Expert	
Learner profile attribute(s)	Reflect on the importance of being a thinker for your learning in this chapter					
Thinkers						

Systems | *Function; Interaction* | *Personal and cultural expression*

8 Do you feel electric?

We are able to **interact**, **communicate** and survive because of natural and artificial **systems** of electrical current.

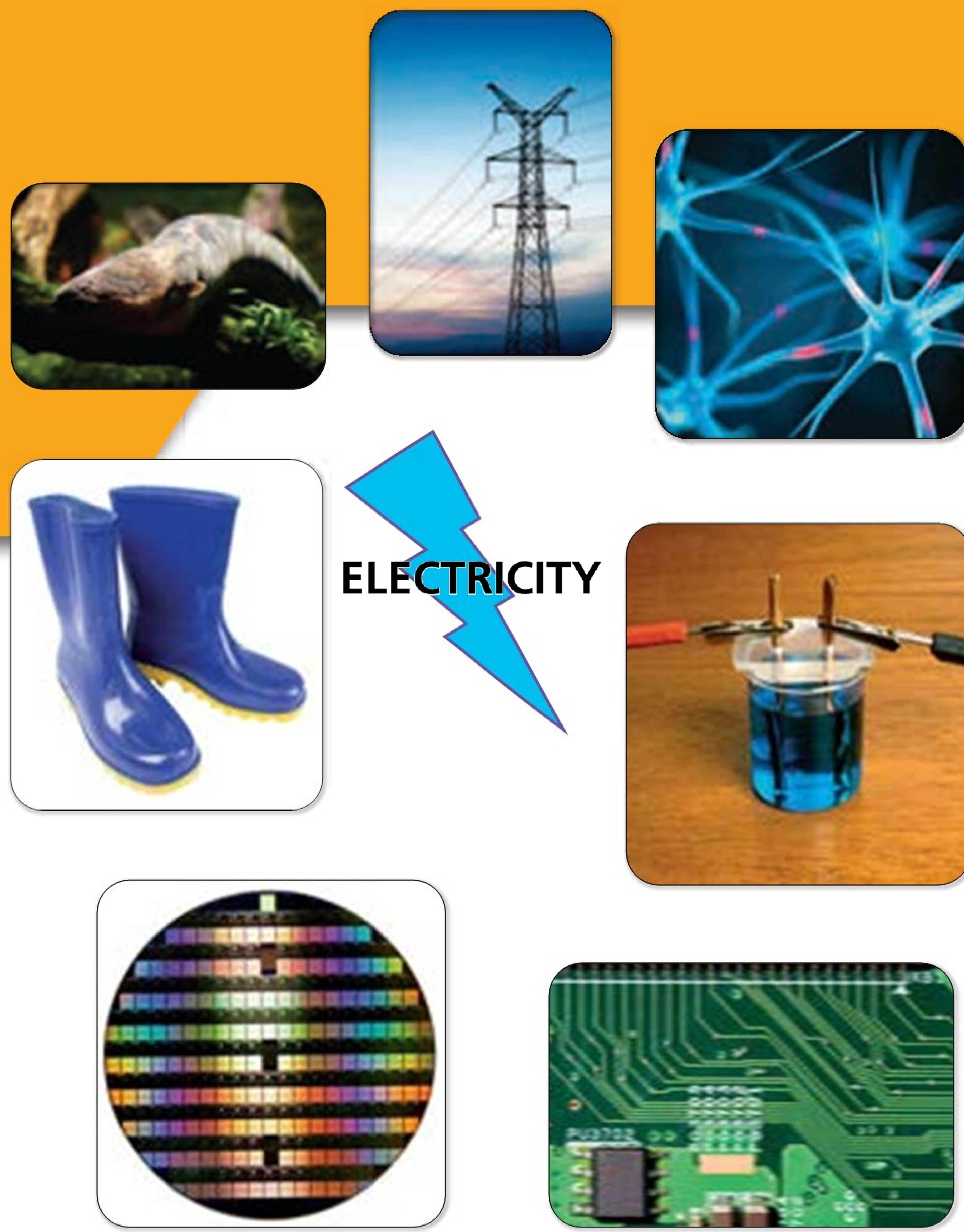


Figure 8.1

CONSIDER THESE QUESTIONS:

Factual: What is electric charge? How do different materials affect electricity? What is the electrical circuitry of the human body?

Conceptual: How can we utilize electric current? How do electrical systems enhance our ability to express ourselves?

Debatable: To what extent does our understanding of electricity improve our lives?

Now **share and compare** your thoughts and ideas with your partner or with the whole class.

IN THIS CHAPTER, WE WILL …

- **Find out** how electricity occurs in nature, how it is made artificially and how humanity uses it to communicate and express ourselves.
- **Explore** how electric circuits work in both artificial and natural systems.
- **Take action** to find out about exciting new possibilities for biological generation of electricity and produce a summary scientific report of these for possible publication.

These Approaches to Learning (ATL) skills will be useful …

- Creative-thinking skills
- Transfer skills
- Critical-thinking skills
- Reflection skills
- Communication skills
- Information literacy skills
- Affective skills

Assessment opportunities in this chapter:

The activities in this chapter will help you develop and evaluate your learning in these MYP Sciences learning objectives:

- **Criterion A:** Knowing and understanding
- **Criterion B:** Inquiring and designing
- **Criterion C:** Processing and evaluating
- **Criterion D:** Reflecting on the impacts of science

KEY WORDS

circuit	output
conduction	process
input	reception
insulation	transmission

We will reflect on this learner profile attribute …

- Risk-takers – we will consider how breakthroughs in the science of electricity were made because scientists were prepared to take risks.

CONNECT–ELABORATE–CLASSIFY

Pulling it together

In this activity, you will draw together or **synthesize** what you already know about this topic and begin to **apply** your understanding to new contexts.

Individually, **review** what you already know about

- **the properties of electrical forces (review Chapter 2)**
- **bonding and electron configuration in different types of material (review Chapter 4).**

In pairs, look at Figure 8.1. What do you think might **connect** the images?

On a copy of the figure, use arrows to connect the images to the lightning bolt in the centre and then write along each of these arrows how they are connected to the central idea.

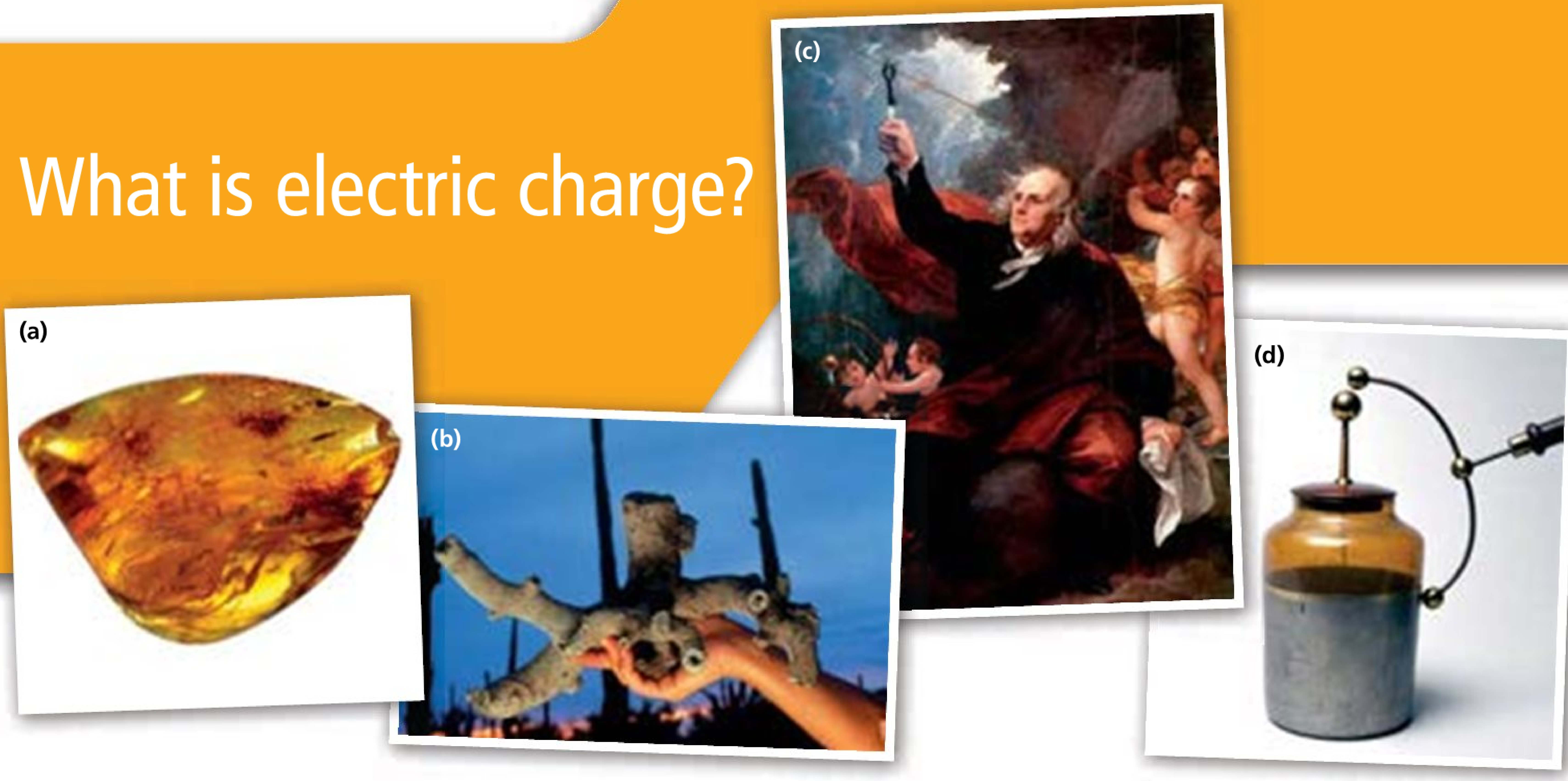
Are any of the images connected to each other in some other way? **Draw** arrows to show these connections. Write along each of these arrows what **connects** the images in this way.

Can you group any of the images together in some way? **Classify** the images by drawing different shapes around them – for example: the 'circle' group; the 'square' group and so on. **Elaborate** your classification by **explaining** how they are connected; for example: 'The square group all …'

Share your ideas with the class.

When we think of electricity, we might immediately think of electrical systems or appliances we use every day. But a second thought might remind us that electricity is also a naturally occurring phenomenon. Later in this chapter we will explore how electrical systems are part of the physiology of biological organisms, enabling living things to respond to their environment, to communicate and express their needs. We will find out about **bioelectrogenesis**, by which living things generate their own electricity. We will also look at how humans have utilized electricity to help them manipulate matter, through **electrolysis** and in the extraction of metals. In the first section we will consider how human beings first came to harness the power of electricity.

What is electric charge?

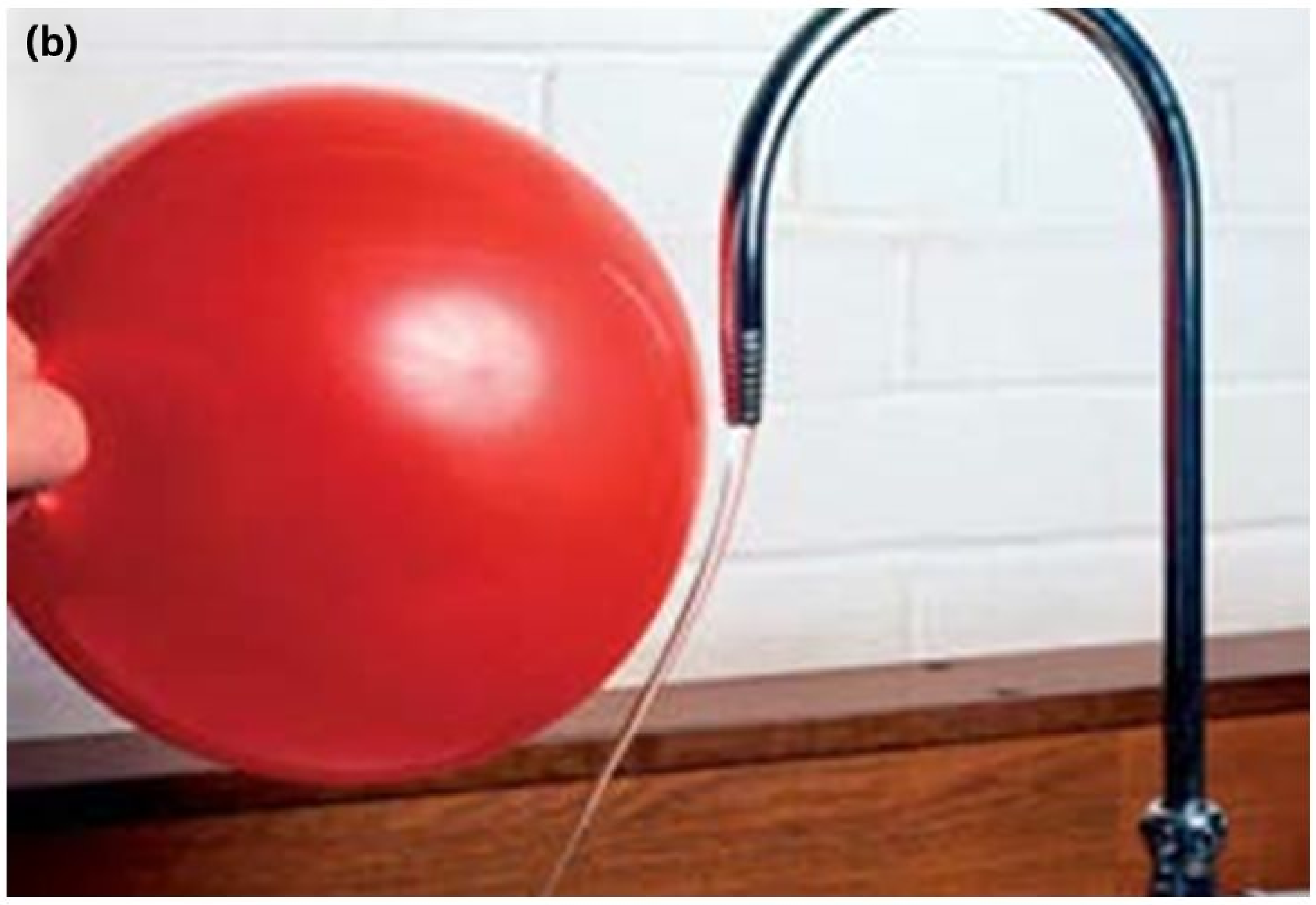


■ **Figure 8.2** (a) Amber; (b) fulgurite; (c) Benjamin Franklin tries to harness lightning; (d) a Leyden jar

Electrical phenomena have been recorded since antiquity; not only the more obvious, such as lightning, but also the electrical properties of certain materials such as amber (Figure 8.2a). Amber is a fossilized tree resin which has been found washed up on the beaches of the countries surrounding the Baltic Sea and elsewhere from prehistoric times to the present day. We know that the ancient Greek philosopher Thales of Miletus (624–546 BCE) recorded the way that amber, when rubbed with wool, can attract other materials and this led all similar phenomena to be classified as 'electric' after the Greek name for amber, *elektra*. The electrical forces produced in materials like amber are usually very weak, but fulgurite (Figure 8.2b) testifies to the huge electrical energies that can be produced by lightning; enough to fuse the quartz of sand into these strange glass structures as massive electric current passes through the earth (see *MYP Sciences by Concept 3:* Chapter 4 for more detail). Not to be deterred, Benjamin Franklin (1706–90) determined to prove that lightning was indeed electricity by proposing to collect electrical charge from storm clouds using a kite. According to Franklin's own report, he was able to observe electricity sparking into his knuckle from a key suspended on the damp kite line, and he was even able to store the charge in a **Leyden jar**, which was a form of **capacitor** or charge storage device (Figure 8.2c,d).

WHAT MAKES YOU SAY THAT?

Look at the images in Figure 8.3. What's going on? What makes you say that?



■ **Figure 8.3** (a) van der Graaff fun; (b) balloon electrickery

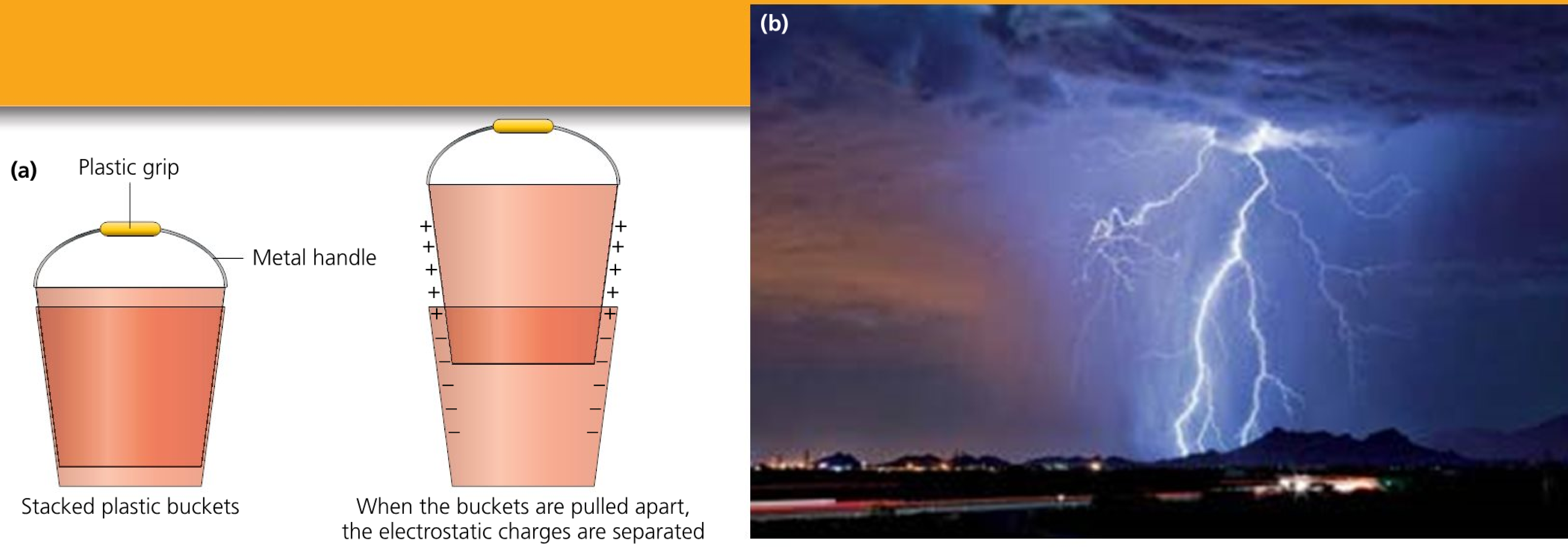


Figure 8.4 (a) Charging by electron transfer in direct physical contact; (b) lightning formation is an example of charging by induction

You may have used balloons to collect static electrical charge through rubbing; this is known as the **triboelectric effect**, in which certain materials allow electrons to transfer into or out of them but not to **conduct** through the material. In Figure 8.3b, electric charges gathered on the balloon are interacting with the **electric dipoles** in the water molecules and a force is produced (see Chapter 4 on polar molecules). Similarly, the van der Graaff generator you may have encountered in *MYP Sciences by Concept 3* gathers large electrical charges on the surface of its dome using triboelectric transfer, and the charge is stored there because the dome is **insulated** from the earth. When a person who is otherwise insulated from their surroundings touches the dome, that charge is conducted into their body and the mutual repulsion of charges between the ends of their hair and their scalp causes their hair to stand on end.

As we saw in Chapter 2, electrical charge is carried by electrons and by protons, with equal but opposite charge values. The charge carried by an electron $e = -1.6 \times 10^{-19}$ C (and so that carried by the proton is $+1.6 \times 10^{-19}$ C.) In uncharged matter, all the electrons are associated with nuclei that carry a balancing positive charge so overall the material is electrically neutral. Matter can become charged where there is a localized surplus or deficit of electrons because it has gained or lost electrons from its neutral state. This can happen if:

- the material has bonds that share electrons over many atoms, i.e. metallic bonds (see Chapter 4)
- the material has long-chain molecules that allow shared electrons to move around
- the material can form ions, for example in a solution (see later this chapter).

In materials where electrons are mobile, static electric charge can also be **induced** without any physical contact, since the electrons will experience the force exerted by an external electrical field and move accordingly (Figure 8.4).

If you would like to review static electrical charges, try this online simulation: **https://phet.colorado.edu/en/simulation/balloons**

Worked example

How many electrons are needed to lift a hair?

We know (see Chapter 2) that the electric force between two charges is given by

$$F = k\frac{q_1q_2}{r^2}$$

Let's estimate the mass of a human hair that is about 10 cm long to be around 5 mg = 5×10^{-6} kg.

That means that the force required to repel the hair is

$$F = mg$$

$$F = 5 \times 10^{-6} \times 10$$

$$F = 5 \times 10^{-5}\ \text{N}$$

If we assume that all the electric charge in the hair is at the far end of the hair, then r = 0.1 m. If we also approximate the constant k to $10^{10}\ \text{N m}^2\ \text{C}^{-2}$ then

$$5 \times 10^{-5} = 10^{10}\frac{q_1q_2}{(10^{-1})^2}$$

Rearranging,

$$q_1q_2 = 5 \times 10^{-17}$$

If we assume the two charges repelling each other are equal in size, then

$$q_1q_2 = q^2$$

So

$$q = \sqrt{5 \times 10^{-17}}$$

We get a charge value of around 7×10^{-9} coulombs.

This doesn't sound very much but we need to remember that electrons carry $e = -1.6 \times 10^{-19}$ C each, so the number of electrons needed to lift our hair might be approximately

$$\frac{7 \times 10^{-9}}{1.6 \times 10^{-19}} = 4 \times 10^{10}$$

So that's over 40 billion electrons!

Ball-park figures, envelope calculations and estimations

Scientists are not always accurate! They often use generalizations and assumptions in order to get a rough estimate of the values involved: a 'ball-park' figure. Estimations of this kind are sometimes useful even if we do not have accurate data on which to base our calculations. Scientists might do this to decide whether a particular inquiry is feasible or to have a rough idea where to look for an answer, which they can then narrow down with greater precision through experimental observation (see Chapter 1).

Notice that we should have rounded the value for e to 2×10^{-19} if we were rounding to consistent precision but we have kept the decimal value just for clarity. However, in the end we have rounded to the nearest factor of 10 anyway.

ACTIVITY: Electrickery explanations

ATL

- Critical-thinking skills: Draw reasonable conclusions and generalizations

In this activity you will **apply** what you know about electric charge to **explain** a magic trick! Search **video electric charge bottle straw** for a video of this experiment.

Explain what is happening in terms of electric charges at each of the stages of the experiment. Thus **explain** why the straw moves.

If the ruler is touched to another dielectric material during the experiment, will it still be able to move the straw afterwards? **Justify** your answer.

Assessment opportunities

- In this activity, you have practised skills that are assessed using Criterion A: Knowing and understanding.

How can we utilize electric current?

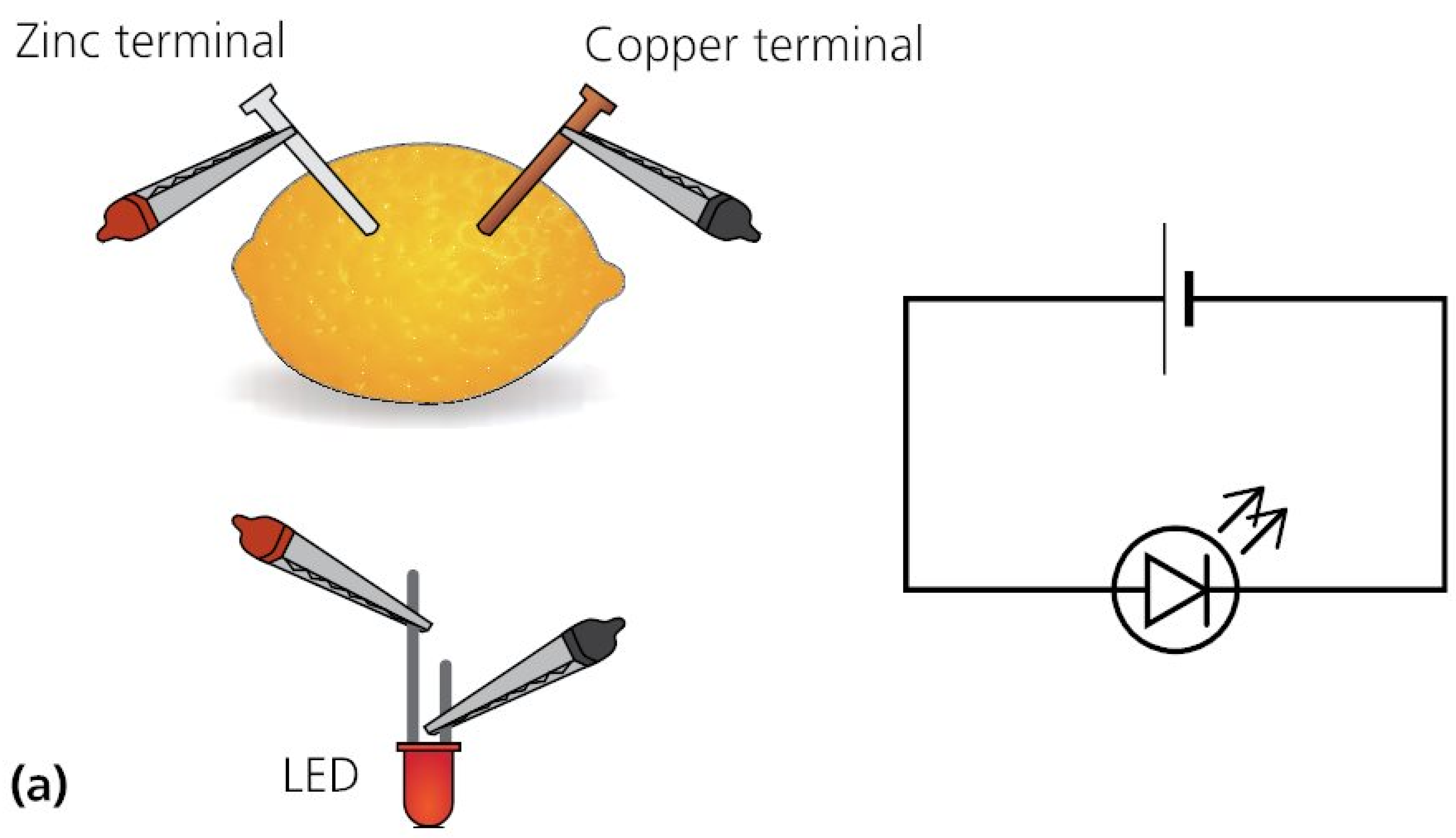
ELECTRICITY ON THE MOVE

Electricity is the result of electrons (or ions) moving such that they cancel a difference in electric charge between two points. When the electrons move they carry kinetic energy and this energy can be used to do useful work. The rate of flow of charge carried by electrons is called an electric current. Sources of electric current include

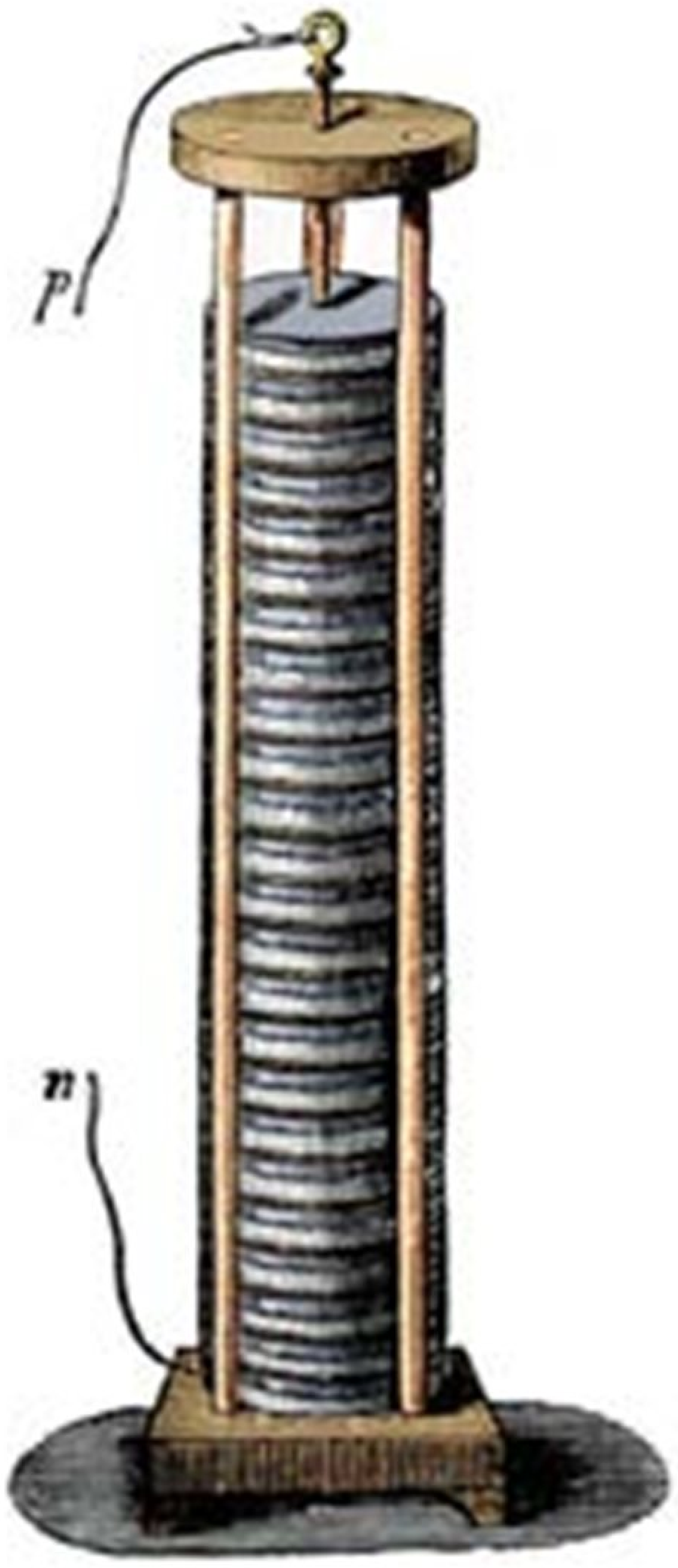
- batteries (combinations of electric 'cells')
- **generators**
- biological processes.

A battery is the name for a collection of electric cells connected together. Cells will typically use chemical processes to liberate electrons from metals in redox reactions. The first cells were produced by Italian scientists Luigi Galvani (1737–98) and Alessandro Volta (1745–1827). You may have made electric cells using citrus fruits and metal electrodes (see *MYP Sciences by Concept 3:* Chapter 4).

Generators use electromagnetic fields to produce current. The first generators were produced by British experimental scientist Michael Faraday (1791–1867) after the work of Danish scientist Hans Christian Oersted (1777–1851) who had discovered that an electric current produced a magnetic field in the space around it.



(a)



(b)

■ **Figure 8.5** (a) A lemon cell uses the action of citric acid on electrodes of different metals; (b) a copy of the first 'pile' or battery made by Alessandro Volta

ACTIVITY: Making electricity

ATL

- Critical-thinking skills: Practise observing carefully in order to recognize problems; Draw reasonable conclusions and generalizations

Observe what happens in the following experiment.

Equipment

- **A strong bar magnet**
- **A solenoid coil**
- **A sensitive ammeter (or 'galvanometer') that can detect current of approximately 5 mA**
- **A spring**
- **Lab stand and clamp**
- **Small masses and mass hanger**

Set up the apparatus as shown in Figure 8.6.

Method

Add masses to the mass hanger so that the magnet is at equilibrium in the centre of the coil.

Pull the masses down and release the system.

Observe what happens to the galvanometer needle.

Experiment with moving the magnet at different speeds and **observe** the size and the direction of the effect on the galvanometer needle.

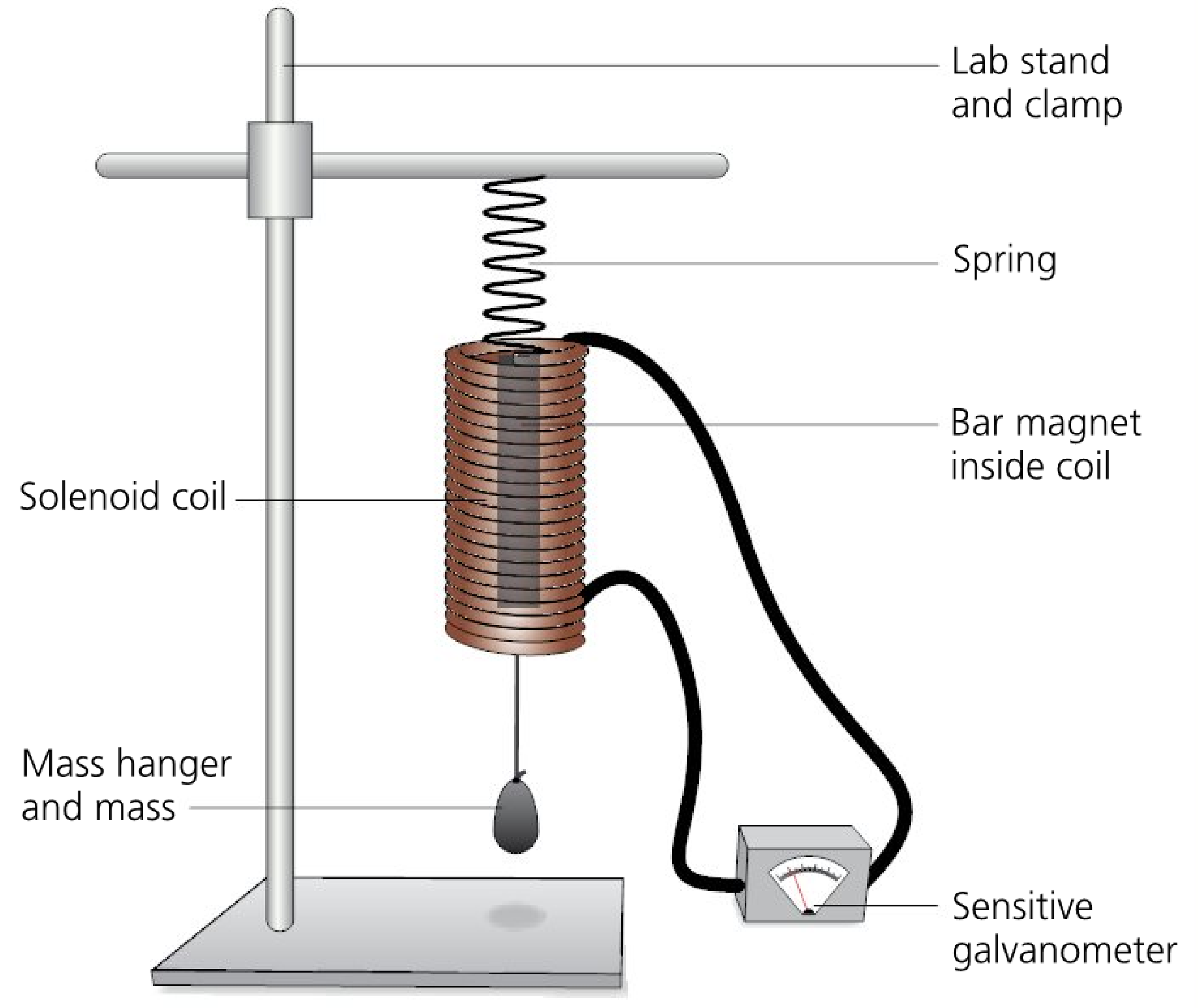


Figure 8.6 Moving magnet induction

Summarize your observations. To what extent was your hypothesis correct?

EXTENSION

If you have an **oscilloscope** available, connect it to the coil instead of the galvanometer. Observe the effect on the oscilloscope trace as the magnet moves up and down through the field. Use a datalogger to record the current and then produce a graph of the data.

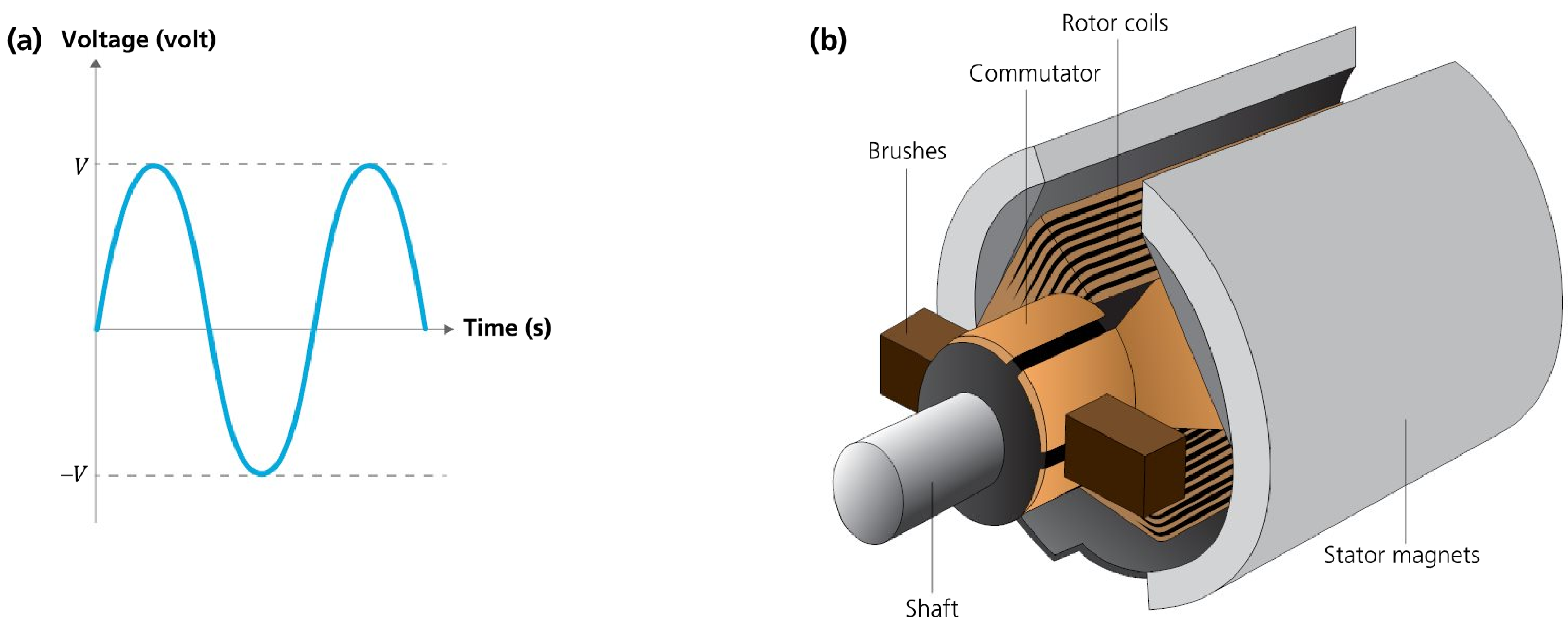


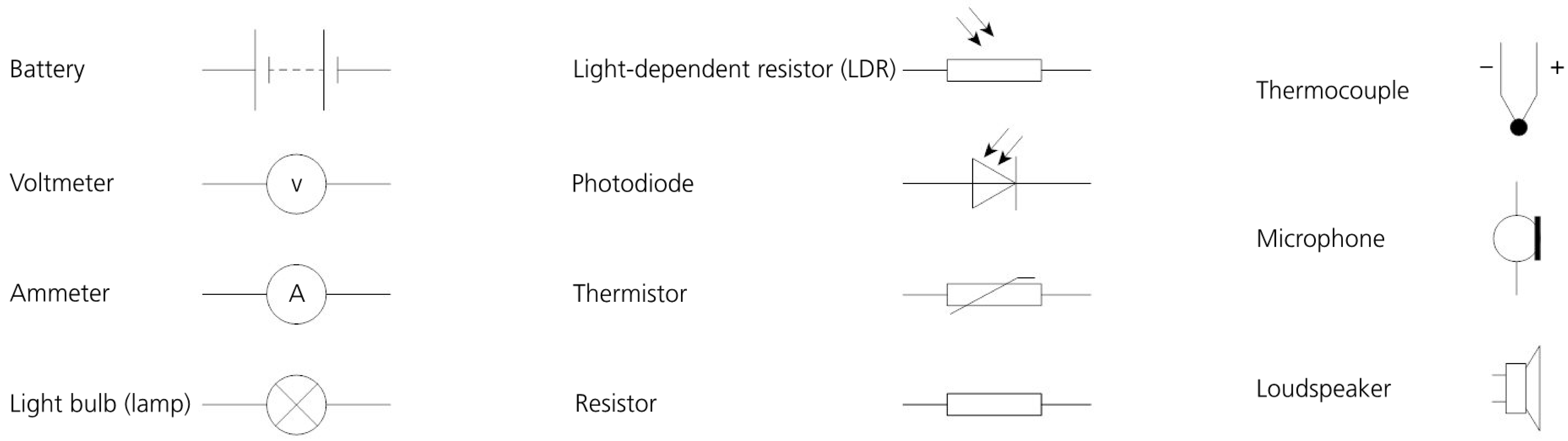
Figure 8.7 (a) Alternating current changes direction, but DC generators (b) use a commutator to limit the current to one direction

Drawing circuit diagrams

When drawing circuit diagrams, follow these simple rules:

- Use **circuit symbols** for the components in the circuit, not drawings (Figure 8.8).
- Draw connecting wires as straight lines.
- Show electrical connections with dots.
- Always draw circuit connections at right angles.

You can find a number of free online apps for drawing circuit diagrams on your computer or tablet device. Search: **circuit diagram maker**.



■ **Figure 8.8** Circuit symbols for components used in this chapter

In the activity *Making electricity* you will have noticed that the direction of the electric current changes with the motion of the magnet in the coil. This produces **alternating current (AC)**.

In power stations, the generators produce electricity continuously by making the magnets rotate. The speed of their rotation affects the variation in the AC output and in most countries the current changes direction 50 times a second, so has a frequency of 50 hertz (Hz). In the USA, the AC frequency is 60 Hz.

Some smaller generators include a device called a **commutator** which 'cuts out' half of the cycle of current (Figure 8.7b). Combined with other electronic components, this can produce a current that flows constantly in one direction: **direct current (DC)**. (See *MYP Physics by Concept 4&5:* Chapter 10 for more!) The current produced by batteries is *always* DC.

We can utilize the energy carried by the current by designing an **electric circuit** that allows electrons to move from a region of relative negative to relative positive charge. The amount of electricity flowing in a circuit is measured as electric current in **amperes** or **amps** for short. The current is then given by the equation

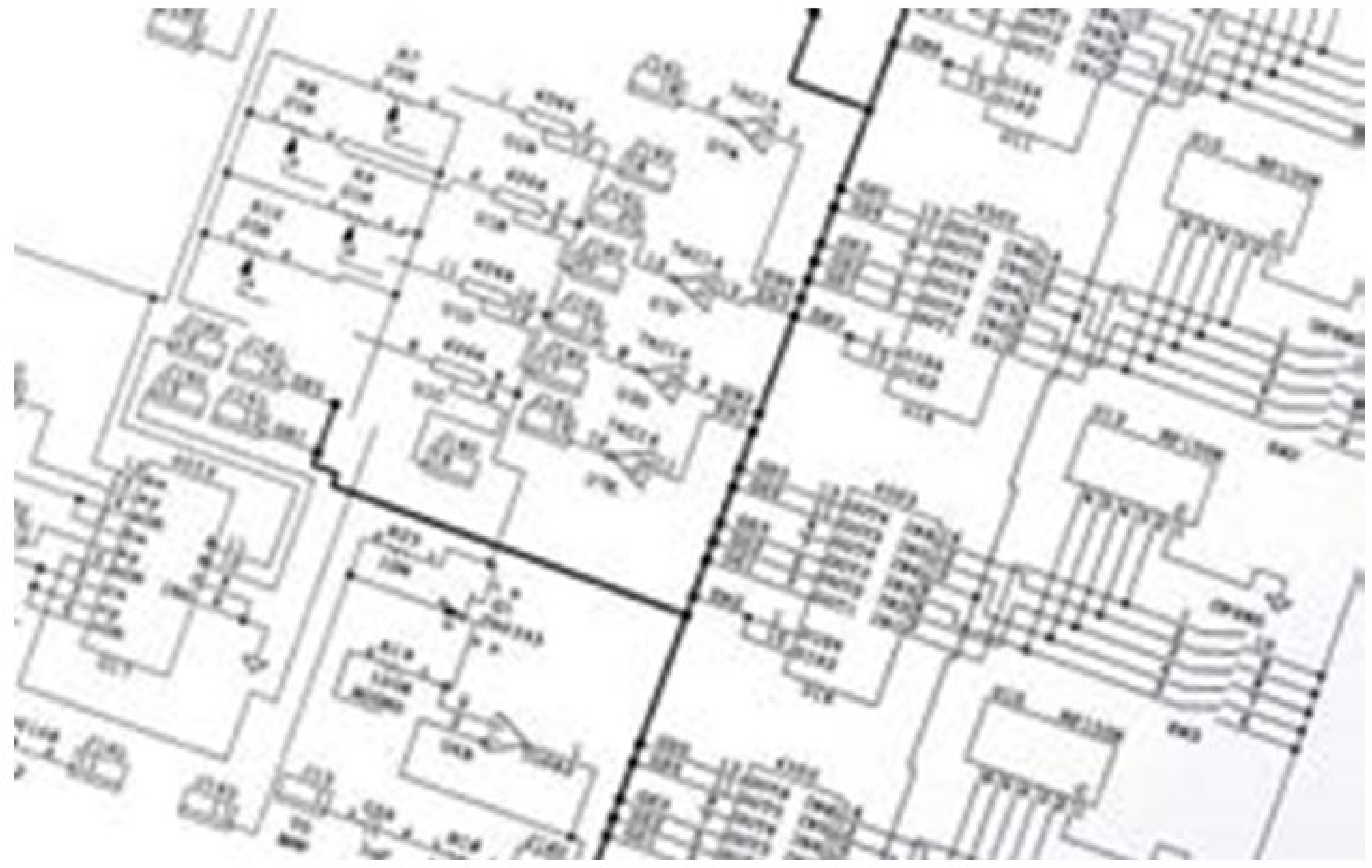
$$I = \frac{Q}{t}$$

where I is current in amps (A), Q is the electric charge flowing in coulombs (C) and t is the time (s).

We can represent circuits by drawing them as they actually look, but this tends to be unreliable and may be misleading. Consequently, scientists and engineers reduce circuits to their most basic schematic form as a circuit diagram.

UNDERSTANDING CIRCUITS

Electrical circuits can seem intimidatingly complex, but they function according to basic principles. In *MYP Sciences by Concept 3:* Chapter 4 we used a river analogy to think about circuits. Another way to imagine electric current is as traffic on a road system, where the vehicles represent electrons. All of these 'analogies' are helpful to use because it can be difficult to conceptualize what is really happening in electric circuits.



■ **Figure 8.9** Part of the circuit diagram for a computer CPU

ACTIVITY: Visualizing electric current flow

ATL

- Creative-thinking skills: Generate metaphors and analogies

Find out about different **analogies** used to help understand **electric circuits**.

Identify the analogy for each of these circuit components: battery/power supply, electric light bulb, narrow wire resistance, parallel circuit branch.

Describe the effect of each of these components on (a) the current and (b) the potential difference.

Use the analogy to **explain** the effect of each of these components.

Evaluate the analogy. How useful is it? Does it have any inaccuracies? What improvements could you make to it? Try to **develop** your own ideas for circuit components in the analogy. Be creative!

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

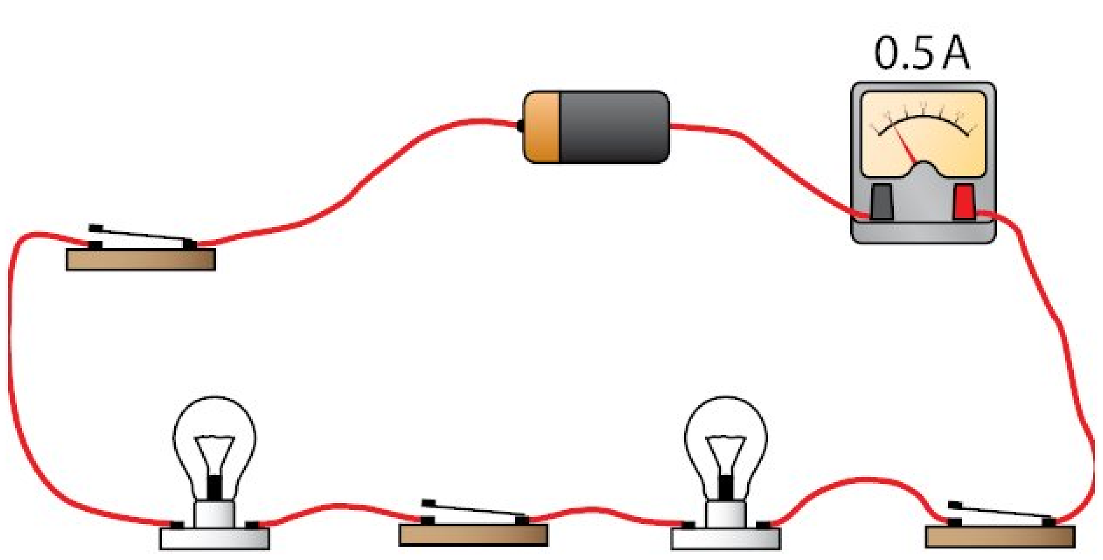
The difference in **electric potential** between two points in a circuit is called the **potential difference** or **p.d.**, measured in **volts (V)**. Sometimes this is called 'voltage' or even 'tension' in high-energy circuits. Potential difference is measured using a voltmeter connected in parallel across two points of a circuit. Similarly, current is measured with an ammeter. Since the current has to actually pass through the ammeter to be measured, the ammeter has to be *in* the circuit in series.

ACTIVITY: The right circuit

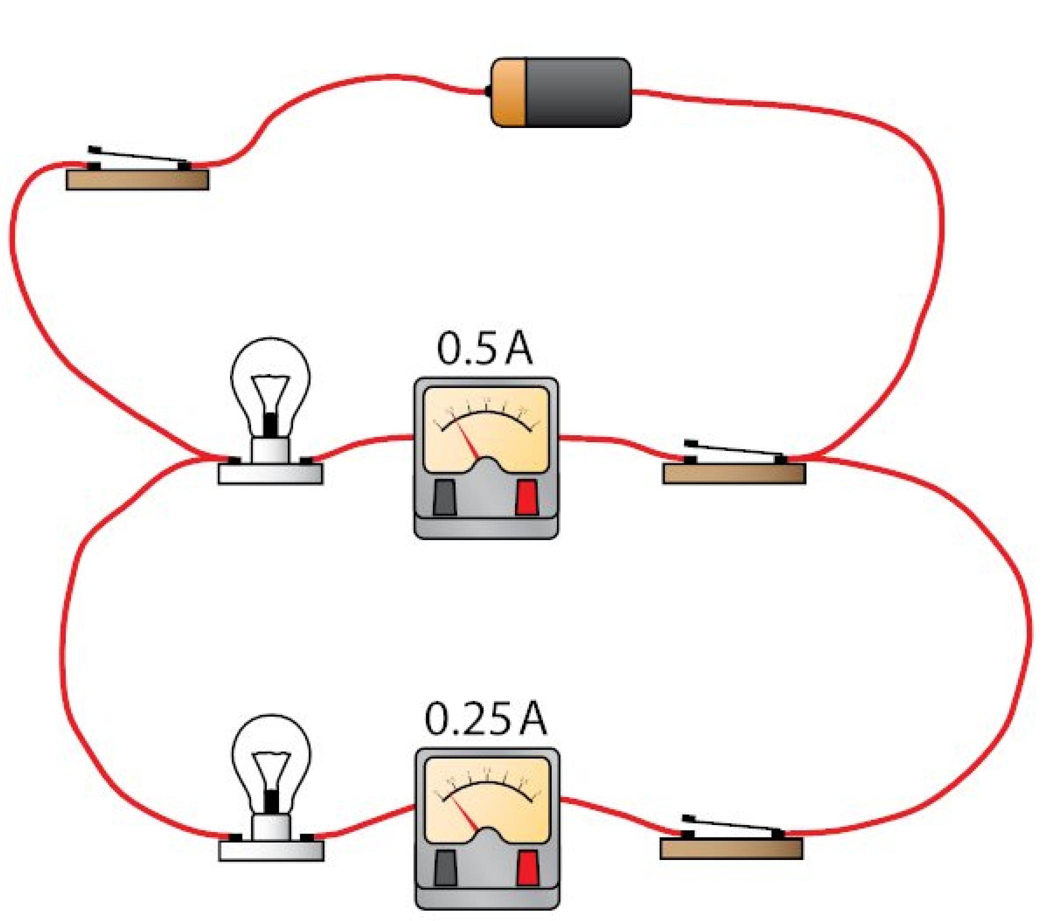
ATL

- Critical-thinking skills: Test generalizations and conclusions

Individually, look at the pictures of circuits below.



■ **Figure 8.10** Series circuit



■ **Figure 8.11** Parallel circuit

Present the two circuits as circuit diagrams.

State which circuit would be best to use for street lighting: series or parallel? **Justify** your answer.

Compare the current flowing in each circuit. **State** which circuit is drawing the most current from the battery.

Calculate the total amount of charge that would flow in each circuit if it was left running for 5 minutes.

Suggest which circuit would run the longest on battery power and **justify** your answer.

The battery in the circuit provides a p.d. of 6 V. In the series circuit, both of the light bulbs have the same resistance.

On your circuit diagram, **show** where a voltmeter could be fitted to measure the p.d. across one of the light bulbs. **State** the p.d. this voltmeter would display.

Explain how you can tell that the bulbs in a parallel circuit do not have the same resistance. **Analyse** the current readings and so **determine** which of the light bulbs must have the higher resistance.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

MEET A SCIENTIST: SIR HUMPHRY DAVY (1778–1829)

Humphry Davy's humble beginnings made him an unlikely candidate for a successful scientist. In the late 1700s, most scientists were men from wealthy families who were formally educated. In contrast, Davy's education was at the local school in Cornwall, England, and all his education was informal. His **inquiring** nature led him to read what is considered to be the first modern chemistry textbook by Antoine Lavoisier. Davy then came up with his own scientific theories, despite having no university education. At the age of 18, he moved to Bristol where he worked on gases (discovering some of the effects of nitrous oxide or laughing gas), before moving to London in 1801. It was here that he began to explore a new field called electrochemistry. He discovered that electricity can be generated from a chemical reaction and he then created electrolytic cells enabling him to split ionic compounds into their elements, leading to the discovery of the reactive alkali metals potassium and sodium, as well as four alkaline earth metals. He was a fantastic **communicator**; he was well known for his flamboyant and exhilarating lectures. His work inspired others, including Michael Faraday, who Davy hired as his assistant after a laboratory explosion caused damage to his eyesight.

■ **Figure 8.12** Sir Humphry Davy

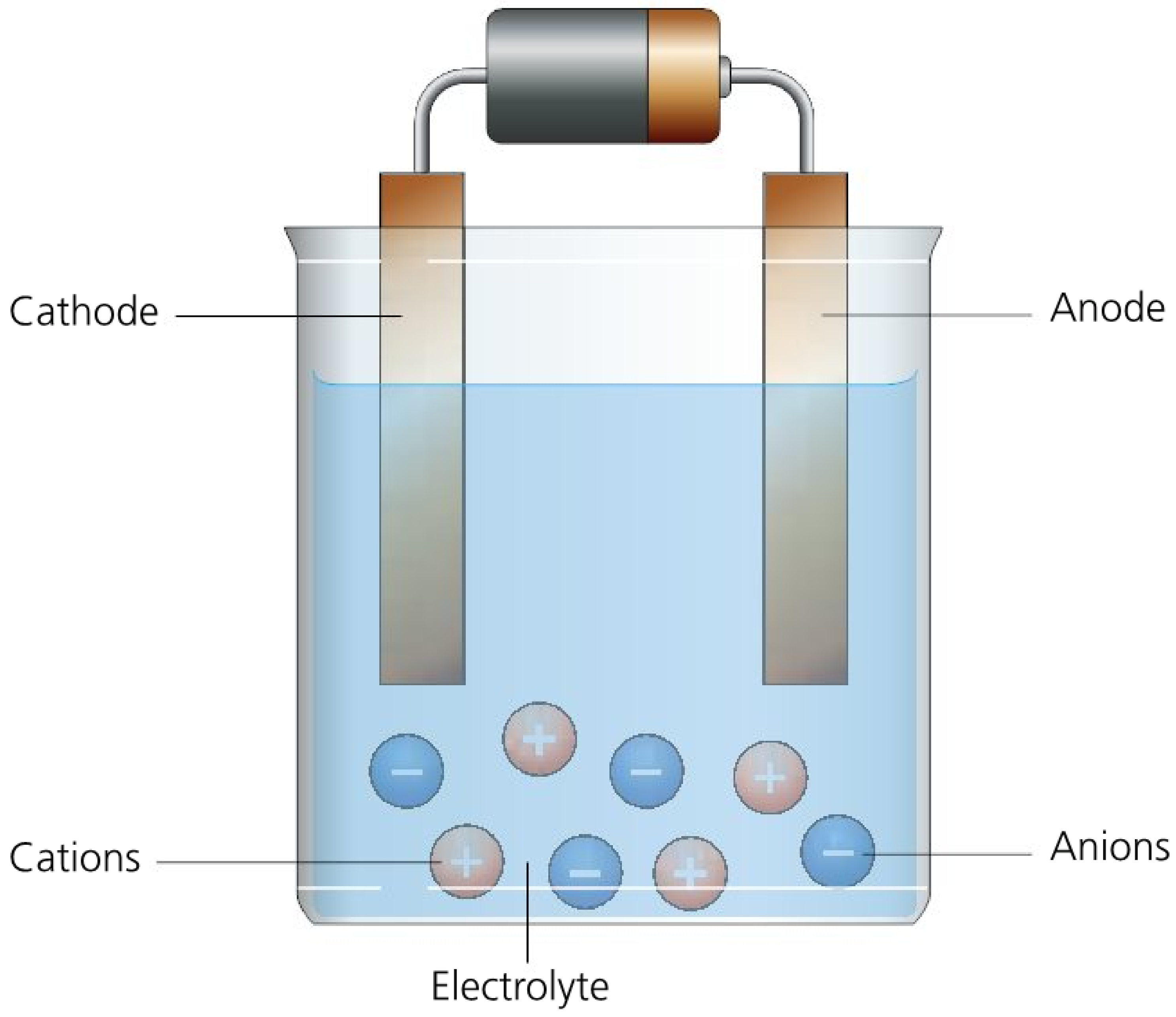
ELECTROLYSIS

Electrolysis is the breakdown of an ionic substance called an **electrolyte**, using an electric current. The electrolyte is an ionic compound in the molten state or dissolved in water (aqueous state), both of which conduct electricity due to the free movement of ions. Sir Humphry Davy electrolysed molten ionic compounds of group 1 and group 2 metals, thereby separating the reactive metals from their compounds. He did this by setting up an **electrolytic cell**. This includes an external source of electrical energy (usually a battery), the electrolyte and **electrodes**. Electrodes are conductors of electricity through which current enters and leaves an electrolyte. In electrolysis, the electrodes are often made of carbon in the form of graphite.

In an electrolytic cell, the electrodes will have a charge depending on which terminal of the battery they are connected to. The electrode connected to the negative terminal is called the **cathode**. The electrode connected to the positive terminal is called the **anode**.

DISCUSS

Why are electrodes commonly made of graphite?



■ **Figure 8.13** An electrolytic cell showing the electrodes and the electrolyte

EXPLANATION GAME

Understanding the products of the electrolysis of molten ionic compounds

Figure 8.13 shows a generic electrolytic cell. Table 8.1 shows the products of electrolysis at each of the electrodes for various electrolytes, all of which are molten ionic compounds.

Electrolyte (molten ionic compound)	Product at cathode (negative electrode)	Product at anode (positive electrode)
sodium chloride	sodium metal	chlorine gas
potassium iodide	potassium metal	iodine gas
magnesium oxide	magnesium metal	oxygen gas
zinc bromide	zinc metal	bromine gas

■ **Table 8.1** Products formed as a result of electrolysing molten ionic compounds

Individually, look at Table 8.1 and consider the following:

- **What do you notice about the trend between the products formed at the cathode and the products formed at the anode?**
- **Why did it happen that way?**

Discuss your conclusions as a class.

REDOX

Electrolytic cells undergo **redox** reactions when electrical energy is applied. Redox is a chemical process where both oxidation and reduction occur. In *MYP Sciences by Concept 2:* Chapter 2 oxidation was defined as a chemical reaction where a substance gains oxygen, while reduction was defined as a reaction where a substance loses oxygen. These definitions cannot be applied to all redox reactions, so a more useful definition of oxidation and reduction is needed.

Our new definitions of oxidation and reduction centre around the gain and loss of electrons and can be applied to a much wider range of redox reactions.

Oxidation **I**s the **L**oss of electrons (OIL).

Reduction **I**s the **G**ain of electrons (RIG).

Oxidation always happens at the anode. The anode (positive electrode) attracts the oppositely charged anions which give up their electrons to form neutral atoms. As electrons are lost, this is an oxidation reaction. Anions tend to be the ions of non-metals, so in the electrolysis of molten ionic compounds, the non-metal ion is always oxidized at the anode.

Reduction always happens at the cathode. The cathode (negative electrode) attracts the oppositely charged cations and provides the electrons that are taken up by the cations to form neutral atoms. As electrons are gained, this is a reduction reaction. Cations tend to be ions of metals, so in the electrolysis of molten ionic compounds, the metal ion is always reduced at the cathode. The reactions that take place during electrolysis can be shown using **half-equations**.

I USED TO THINK … NOW I THINK …

Redefining the terms oxidation and reduction

1. **Formulate a word equation for the reaction of magnesium and oxygen.**
2. **Formulate why this can be described as an oxidation reaction, using the definition from *MYP Sciences by Concept 2*.**
3. **Formulate a formula equation for this reaction, making sure you also include state symbols.**

Hint

In you are not sure how to do this, refer back to Chapter 4.

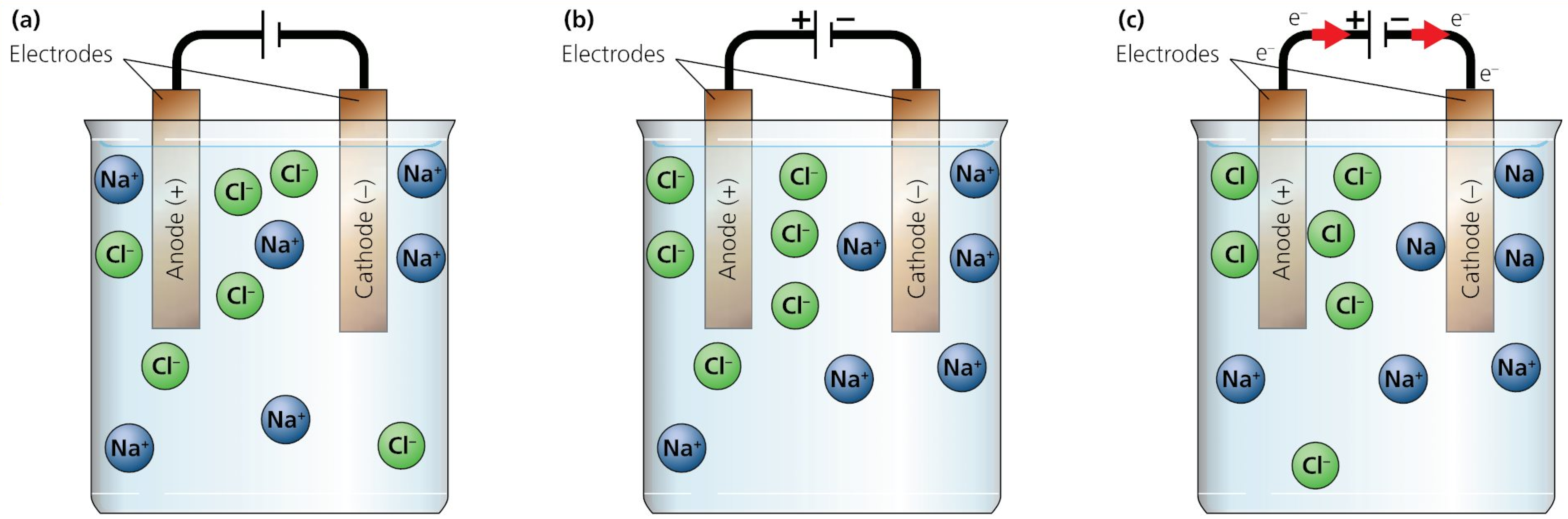
4. **Describe what has happened to the magnesium. Use the words *atom*, *ion* and *electron* in your answer.**
5. **Suggest a new definition for oxidation.**
6. **Repeat steps 3 and 4 for the oxygen. Use your new definition for oxidation and the fact that reduction is the opposite of oxidation to suggest a new definition of reduction.**
7. **Evaluate which definition of oxidation and reduction is more useful, the one used in *MYP Sciences by Concept 2* or your new one.**

Hint

To help you remember which process occurs where, try to make up a mnemonic. For example, Chemists Really Are Okay will help you remember the Cathode–Reduction, Anode–Oxidation pairs.

EXTENSION

Redox doesn't just happen in electrolysis. The change in colour of the Statue of Liberty is the result of the original copper undergoing oxidation reactions. Watch this video to find out more: **www.youtube.com/watch?v=_ZSLrXtg1-o**



■ **Figure 8.14** (a) The electrolysis of molten sodium chloride. The electrolyte is made up of free moving ions. (b) The cations (metal ions) are attracted to the negatively charged electrode (cathode) while the anions (non-metal ions) are attracted to the positively charged electrode (anode). (c) The anions (non-metal ions) lose electrons at the anode (oxidation); these travel through the circuit to the cathode, where the cations (metal ions) gain electrons (reduction). Neutral metal and non-metal atoms are formed.

Worked example

How to work out half-equations

Follow these simple rules to help you work out the individual half-equations of a redox reaction.

1. **Determine** the formula of the reactant (the ion in the electrolyte) and the formula of the final product (the neutral atom or molecule formed at the electrode).
2. Put the reactant and product in an equation, separated by a forward-facing arrow.
3. Balance the equation.
4. Count the overall charge on each side. Add electrons in order to make the charge on both sides the same.
5. **State** whether the half-equation is an oxidation or reduction reaction.

For example, write a half-equation for the conversion of silver ions to silver metal.

Step 1: Reactant – Ag^+ (l); product – Ag (s)

Step 2: Ag^+ (l) → Ag (s)

Step 3: The equation is balanced.

Step 4: Total charge on the reactant side is +1. Total charge on the product side is 0 (neutral atoms have no charge). So one electron needs to be added to the reactant side to bring the 1+ charge down to 0 : Ag^+ (l) + $1e^-$ → Ag (s)

Step 5: As electrons have been gained, this is a reduction reaction.

Now try this more complex example: write a half-equation for the conversion of chloride ions to chlorine gas.

Step 1: Reactant – Cl^- (l); product – Cl_2 (g)

Hint

While each chloride ion will form an individual chlorine atom, chlorine is diatomic, so two atoms will combine to form a chlorine molecule. The final product is, therefore, a chlorine molecule.

Step 2: Cl^- (l) → Cl_2 (g)

Step 3: $2Cl^-$ (l) → Cl_2 (g)

Step 4: Total charge on the reactant side is –1 × 2 = –2. Total charge on the product side is 0 (neutral atoms have no charge). So two electrons need to be added to the product side to bring the 0 charge down to –2: $2Cl^-$ (l) → Cl_2 (g) + $2e^-$

Step 5: In this reaction, the chloride ions are losing electrons in order to become neutral. However, conventionally, we never show electrons as being lost (– e^-), so they are shown as being gained on the product side. As the chloride ions are losing electrons, this is an oxidation reaction.

EXTENSION: GOING FURTHER

The redox equation is the combined result of the oxidation and reduction half-equations. However, in the final redox equation, the same number of electrons must be gained and lost. If this is not the case in the two half-equations, all of the components of each half-equation need to be multiplied by a factor that will result in there being an equal number of electrons gained and lost. Then, the two half-equations are added together, leaving out the electrons. Can you write a redox equation for the electrolysis of molten potassium bromide?

If you have managed to get your head around that, well done. It is about to get a bit more complicated. We will now introduce two new terms, **reducing agent** and **oxidizing agent**.

- A reducing agent is the substance that is oxidized.
- An oxidizing agent is the substance that is reduced.

In the worked example on page 199, the Ag^+ ions gained electrons (were reduced), so they would be an oxidizing agent. The Cl^- ions lost electrons (were oxidized), so they would be reducing agents.

ACTIVITY: Half-equations

ATL

- Reflection skills: Consider ATL skills development
- Transfer skills: Apply skills and knowledge in unfamiliar situations; Combine knowledge, understanding and skills to create products or solutions

Formulate half-equations for the following reactions. **Determine** whether the half-equation is showing oxidation or reduction and, using this, **deduce** whether the substance is an oxidizing or reducing agent. **State** at which electrode the reaction will happen.

1 **Potassium ions to potassium metal**
2 **Bromide ions to bromine gas**
3 **Hydrogen ions to hydrogen gas**
4 **Lead ions to lead metal**
5 **Aluminium ions to aluminium metal**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

EXTENSION: GOING FURTHER

What happens if your electrolyte is a solution of the ionic compound? Are the products still the same as if you are electrolysing the molten ionic compound? The answer is no, because some of the water molecules in the solution have the ability to split up into H^+ and OH^- ions (Chapter 6) resulting in competition at the electrodes.

The winners of the competition, and thus the products that form at the electrodes, are:

- At the cathode where the metal ions compete with H^+ – the least reactive substance will gain the electrons and become neutral atoms, while the more reactive remains in the solution as ions.
- At the anode where the non-metal ions compete with OH^- – if the non-metal ion is a halogen, the halogen loses the electrons. If it is not a halogen, oxygen is formed from the OH^- ions.

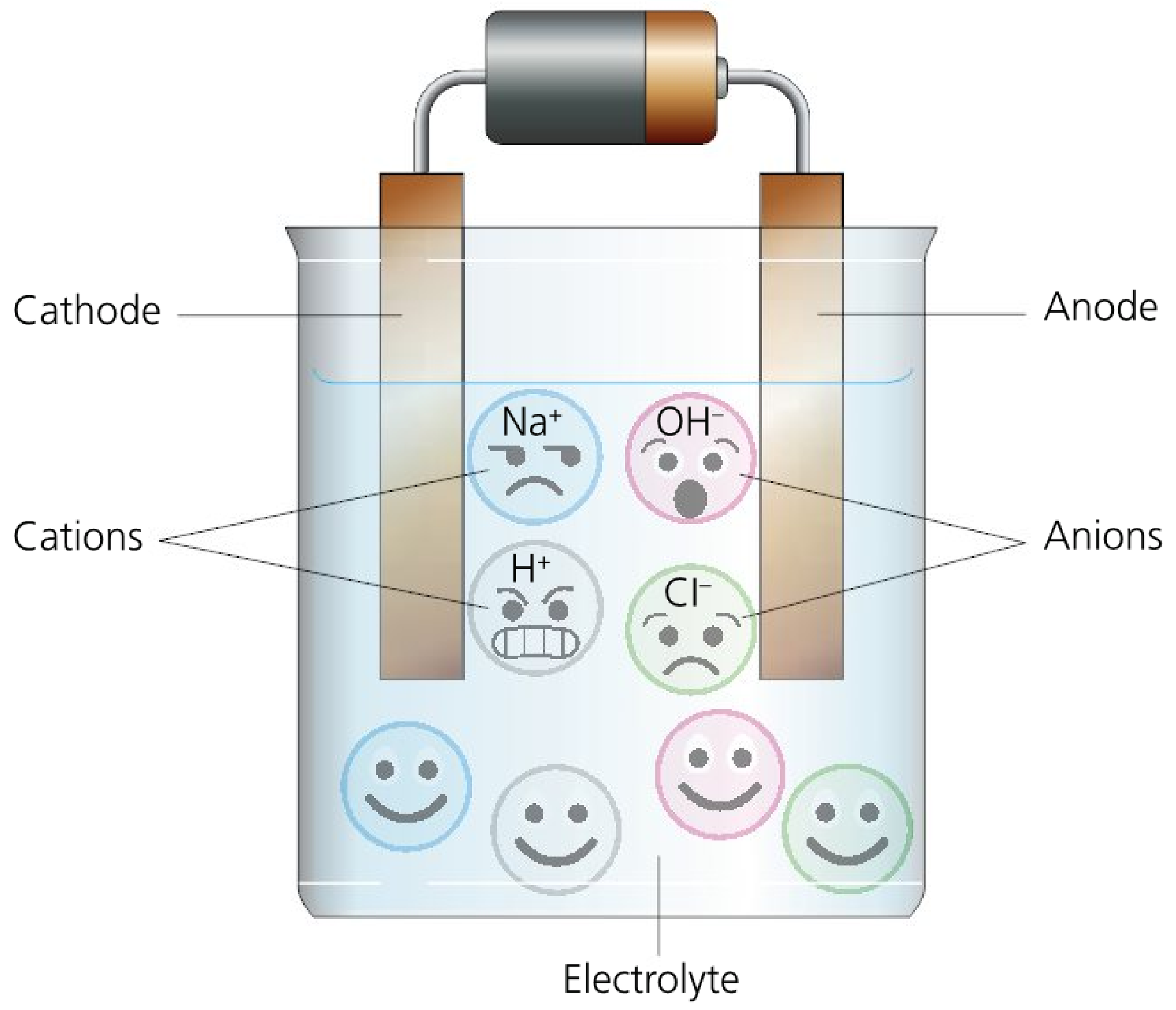


Figure 8.15 In the electrolysis of sodium chloride solution, who will gain electrons and who will lose? To find out learn some simple rules!

Most reactive

Potassium	K
Sodium	Na
Calcium	Ca
Magnesium	Mg
Aluminium	Al
Zinc	Zn
Iron	Fe
Tin	Sn
Lead	Pb
Hydrogen	H
Copper	Cu
Silver	Ag
Gold	Au
Platinum	Pt

Least reactive

Figure 8.16 The reactivity series. While hydrogen is not a metal, it can be included in the reactivity series to predict which metals will react with acids. Here, it helps us predict the products of electrolysis reactions of solutions.

ACTIVITY: Electrolysis to provide the fuel of the future?

ATL

- Communication skills: Read critically and for comprehension; Read a variety of sources for information and for pleasure; Make inferences and draw conclusions; Paraphrase accurately and concisely

As we saw in Chapter 5, our reliance on fossil fuels as our major energy source is increasingly problematic. One potential alternative fuel is hydrogen.

Figure 8.17 Is hydrogen the fuel of the future?

Hydrogen is produced by the electrolysis of water, which splits up into oxygen and hydrogen gas. Watch the video here to find out more about the process: **www.youtube.com/watch?v=38ULHoKWZag**

Your task is to write a report to the International Atomic Energy Agency, advising them about the potential of hydrogen being THE fuel of the future. In your letter you must:

- **Explain the science behind the electrolysis of water, using your knowledge of redox.**
- **Evaluate the potential of hydrogen as a reliable fuel. Make sure to discuss the advantages and disadvantages, linking these to any social, environmental, political, moral, ethical, cultural or economic issues that are relevant.**
- **Complete your work by documenting the sources you have used in a bibliography.**

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

■ **Figure 8.18** Copper electrodes in a copper refinery

DISCUSS

What would the products of the electrolysis of copper (II) sulfate solution be using graphite electrodes?

HOW CAN WE PURIFY METALS?

Changing the electrolyte from a molten ionic compound to the compound in solution affects the products formed. Changing the material of the electrodes can also have consequences on the outcome of the electrolysis reaction.

The electrolysis of copper (II) sulfate solution, using copper electrodes instead of graphite electrodes results in copper being transferred from the anode to the cathode. Industrially, using unrefined copper at the anode and pure copper at the cathode builds up pure copper at the cathode, essentially purifying the impure copper that was originally at the anode. This is a process that is fundamental to creating copper at the level of purity needed in today's market. After copper is extracted from its ore, it can be over 99.5 per cent pure, but even this level of impurity will reduce the conductivity of the metal significantly. So copper undergoes a process of electrolytic refining in order to increase its purity to 99.99 per cent. Copper can be used to coat a cathode made of a different metal in a process called **electroplating**. Electroplating is a process by which a metal object is coated with a layer of another metal through electrolysis, and it has significant industrial uses. Copper, chromium, silver and tin are the most common metals used for electroplating.

ACTIVITY: Make it pure!

ATL

- Information literacy skills: Collect, record and verify data; Present information in a variety of formats and platforms
- Critical-thinking skills: Interpret data; Draw reasonable conclusions and generalizations

In groups you will **explore** what happens when you pass an electric current through a solution of copper (II) sulfate. You will be using two pieces of copper as your electrodes, **measuring** their mass before the experiment and then again at the end, and looking at any changes in mass that occur.

Equipment and materials (per group)

- **A DC power supply (power pack or 1.5 V battery in its holder)**
- **Two crocodile clips**
- **Two connecting leads**
- **A 250 cm^3 beaker**
- **Two strips of copper (these need to be long enough to fold over the top of the beaker and reach about $\frac{2}{3}$ of the way down the beaker)**
- **Copper (II) sulfate solution, 0.5 M**
- **Electronic balance**
- **Permanent marker**

Safety: Wear eye protection and wash your hands at the end of the experiment. Copper (II) sulfate is considered harmful if ingested and corrosive if it comes in contact with eyes between the concentrations of 0.2 M and 1.0 M. If the solution splashes into your eyes, wash with eyewash. If it splashes onto your skin, wash with plenty of water.

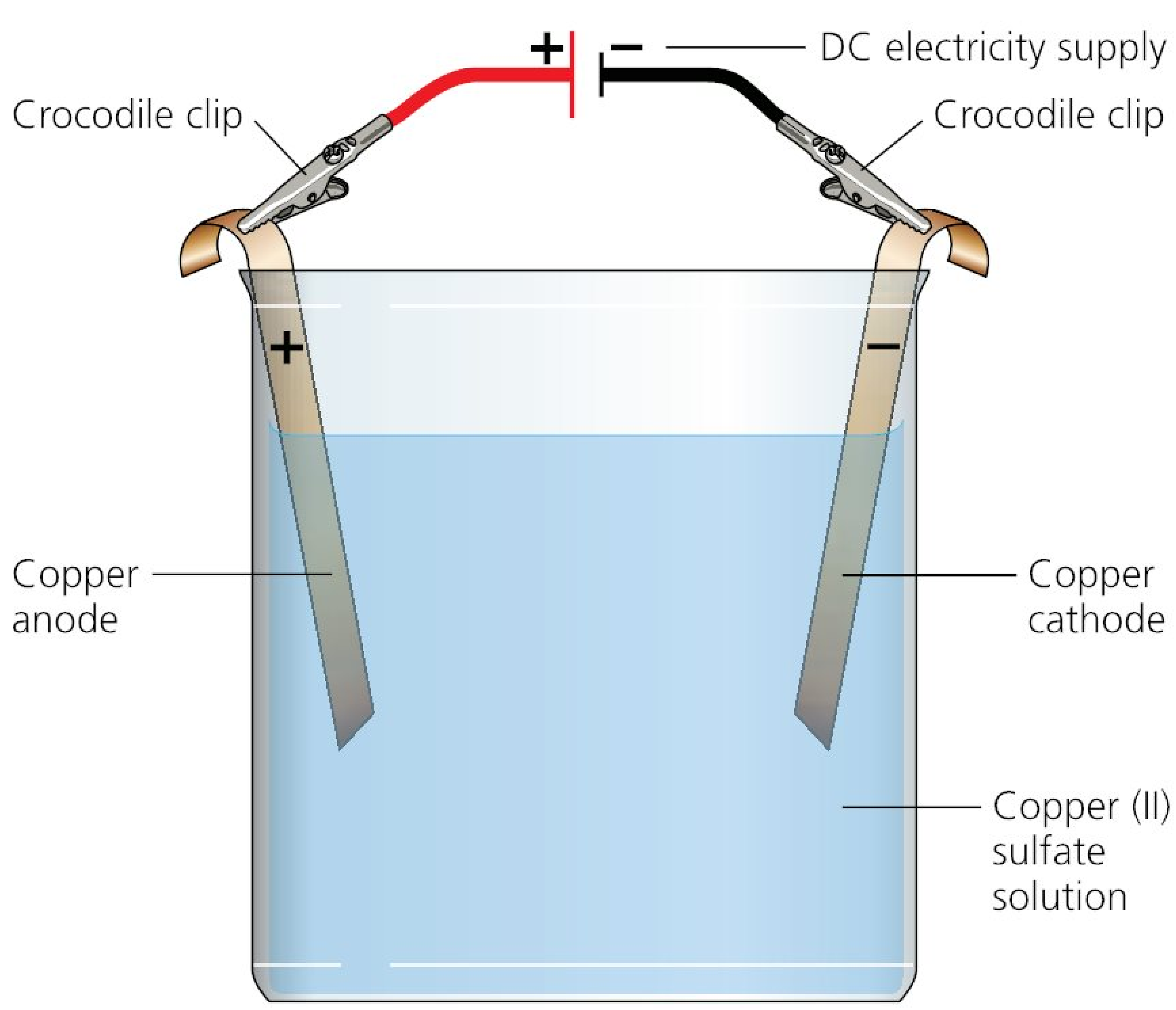
Method

1. **Label the top of the two copper strips '+' and '–' with the permanent marker. The '+' copper strip will be the anode and the '–' copper strip will be the cathode.**
2. **Design a table to record your results. Remember to include headings and units.**

THINK–PAIR–SHARE

How often do you use electroplated items?

3 **Set up the apparatus as shown in Figure 8.19, taking care to connect the labelled electrodes to the correct terminals of the power supply.**
4 **Half-fill the beaker with copper (II) sulfate solution, or add enough to make sure at least $\frac{1}{3}$ of the copper strips are submerged.**
5 **Connect the batteries to the electrodes. If using a power pack, set the p.d. to 1 V before turning on.**
6 **Let the current run for at least 20 minutes before disconnecting the circuit and patting the copper strips dry with a paper towel. Record any qualitative observations in your notes and quantitative results in your table.**



■ **Figure 8.19** Set-up of the electrolytic cell

Analyse your results by **calculating** the change in mass of the two copper strips. **Describe** how the masses have changed and **explain** the chemical process at each electrode using appropriate half-equations.

Evaluate the procedure and **suggest** ways in which you might extend this investigation.

◆ Assessment opportunities

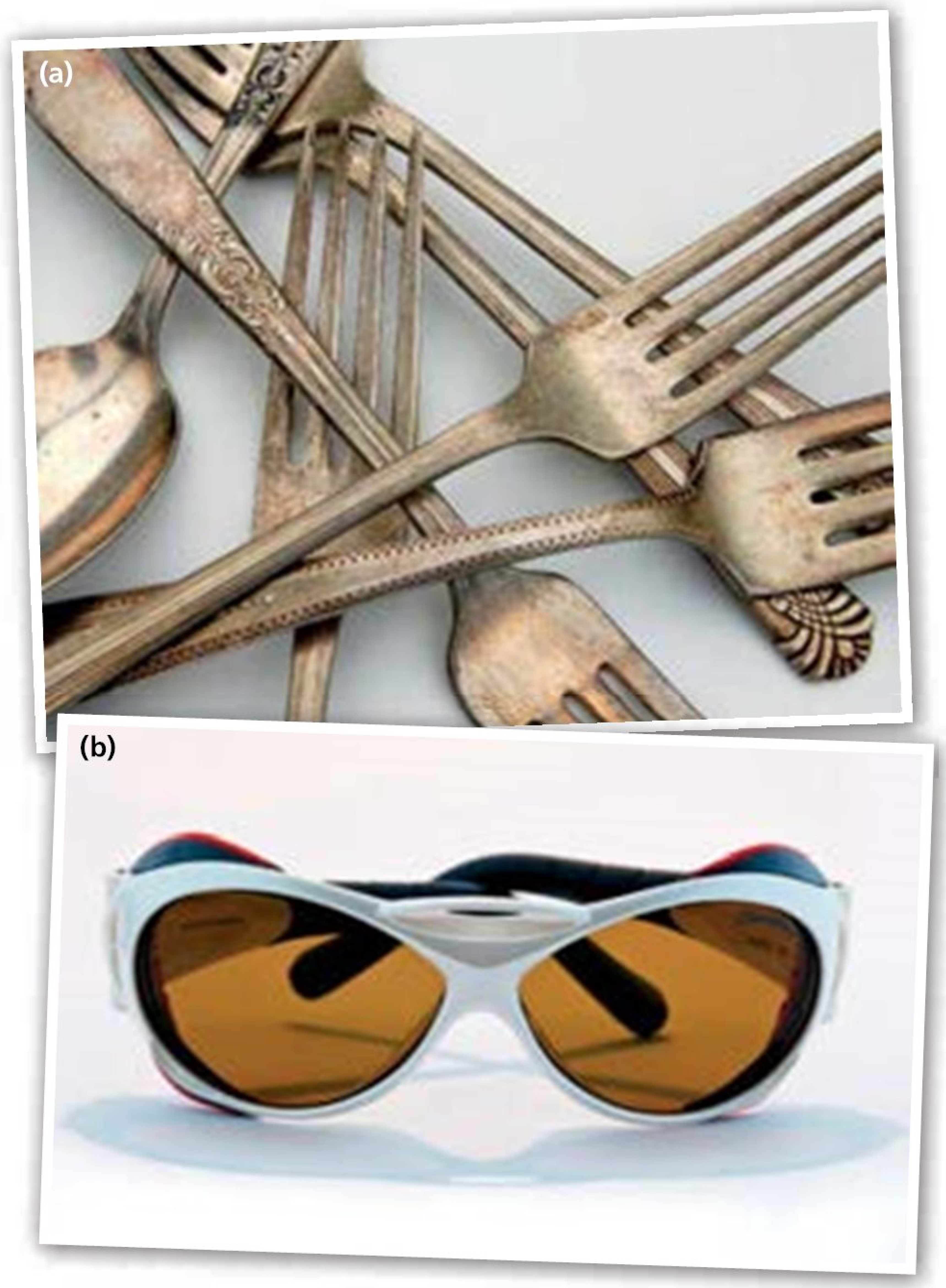
- In this activity you have practised skills that are assessed using Criterion C: Processing and evaluating.

Hint
Objects found in the kitchen are a good place to start.

In pairs, **compare** your answers. **Discuss** the benefit of electroplating these items. **Share** your ideas as a class.

OTHER USES OF REDOX

One other extremely important use of electrolysis industrially is in the extraction of some of the most reactive metals in the periodic table from their ores. This will be further explored in Chapter 10. However, redox isn't restricted to electrolysis or industrial processes, in fact it is happening all around us and even inside our cells all the time. Figure 8.20 shows some examples.



■ **Figure 8.20** Redox is (a) the tarnishing of silverware because of atmospheric oxygen; (b) the reason why photochromic lenses show different colours in direct sunlight and in the shade

EXTENSION

Research aims to harness the electricity produced by our bodies! Some gyms use exercise bike stations to harvest energy from workouts. We also aim to power small devices or wearables using the energy generated by our bodies while walking and moving. Find out more about harnessing this kind of electricity.

HOW DO LIVING THINGS UTILIZE ELECTRICAL CURRENT?

We have seen how humanity has learnt to harness electricity and use it in different ways, but humans cannot claim to be entirely original in this. Many living things in the natural world have their own electrical systems and the human body too has its own circuitry. There are many different species of electric fish, like the electric catfish, the torpedo ray and the electric eel which use their own electrocommunication systems. Some of them are **electrogenic** and can produce electricity while others are **electroreceptors** and can detect electric fields. Fish use these electrical systems to survive and protect themselves or communicate or reproduce. There are other organisms, like bacteria, which produce electricity and this is known as **bioelectrogenesis**. **Piezoelectricity**, which is a phenomenon in which electricity is created when subjecting certain materials to pressure, has been used to produce electricity from a virus, which was then genetically modified to make it generate electricity and power a liquid crystal display. This piezoelectric energy generation has the potential to generate and use electricity in an environmentally friendly manner.

We can use electroreception characteristics to deter dangerous animals. For example, some devices worn by surfers and sea-adventurers create an electric field around them in order to deter sharks. Many research investigations have been conducted to assess the efficacy of such devices.

ACTIVITY: Do electric shark repellents work?

ATL

- Transfer skills: Apply skills and knowledge in unfamiliar situations; Inquire in different contexts to gain a different perspective; Combine knowledge, understanding and skills to create products or solutions

Figure 8.21 Great white!

Imagine you are going on a long surfing holiday and you will be at sea every day. The area you are going to has had a number of incidents of great white shark attacks. You heard about some commercial electric shark deterrents and you decided to use your scientific skills to decide whether or not they are likely to be effective.

Find out about the electroreception characteristics of great white sharks and research **shark repellent** to identify the different brands, some of which have attracted scientists to conduct research and publish articles on their effectiveness. **Evaluate** the evidence and conclude whether you are confident such devices work and which one you will pick. Since you will be buying this, you should also consider the cost!

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion D: Reflecting on the impacts of science.

How do different materials affect electricity?

ACTIVITY: Realizing the potential

ATL

- Critical-thinking skills: Practise observing carefully in order to recognize problems; Interpret data; Draw reasonable conclusions and generalizations

What determines the amount of electric current flowing through a conductor? We already know that a potential difference across the conductor is required to make the electrons move and carry energy. But what is the effect of the conductor material?

In this activity you will work as an electrical engineer for an electricity supply company. The company needs information on the best kind of electrical conductor to use for the cabling it needs to supply electricity.

■ **Figure 8.22** Industrial and domestic cables

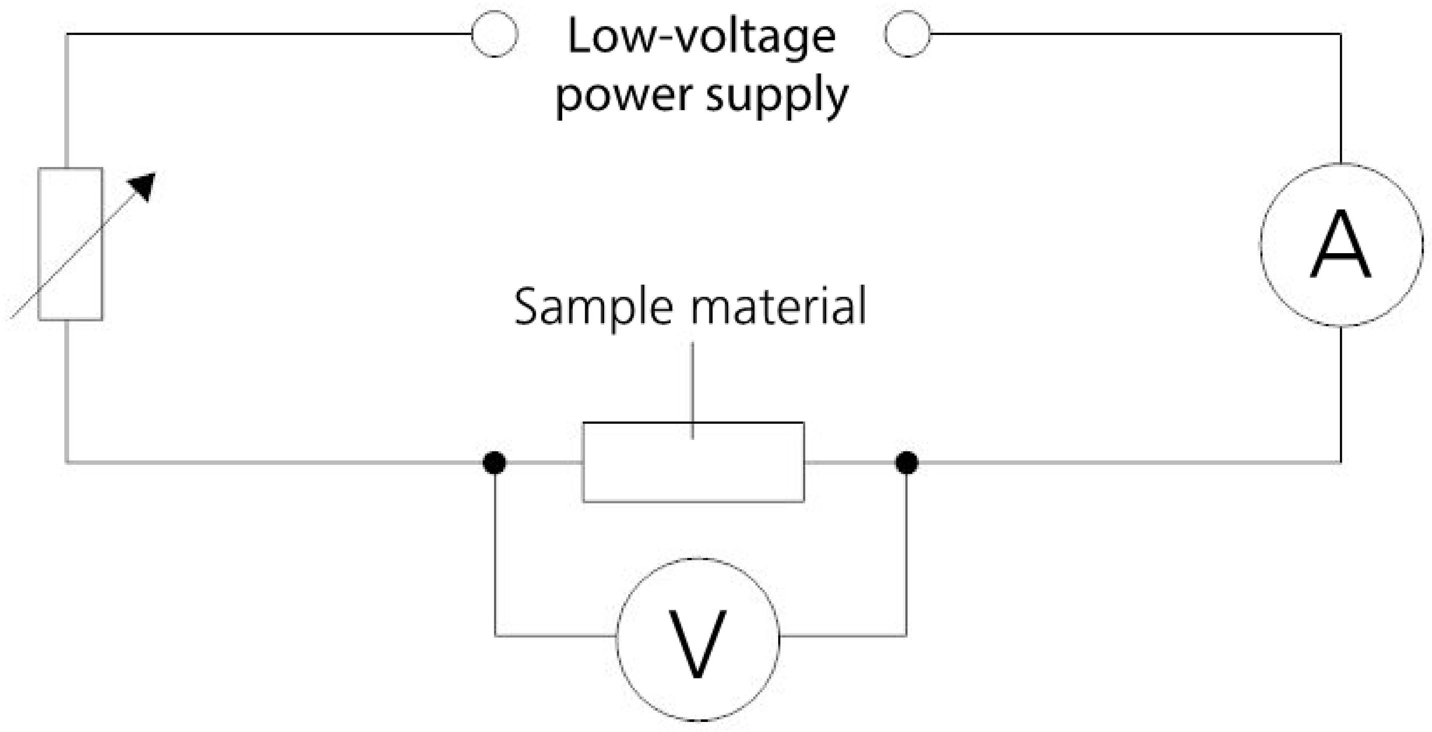
Inquiry: To investigate the effect of conducting material on the electric current

Equipment

- **Voltmeter**
- **Ammeter**
- **Connecting wires and two connecting clips**
- **Power supply unit or battery pack**
- **Variable resistor (rheostat)**
- **Various pieces of conducting wire (your teacher will supply these)**

Method

Connect the circuit components as shown in Figure 8.23.



■ **Figure 8.23** Circuit diagram

Connect *one* of the conducting materials between the connecting clips in the circuit as shown.

Variables

Discuss: What independent variable will you change in this experiment? How will you change it? How will you measure its value?

What dependent variable will you **measure**?

What must be controlled/kept the same?

Hypothesis

Suggest a relationship between the independent and the dependent variables you have identified. **Justify** this hypothesis in terms of what you know about electric current in circuits.

Carry out preliminary measurements with a sample of material and decide on the appropriate range and interval for your readings before you begin.

Look carefully at the meters you have been provided with. What is the smallest measurement they can make? This is called the minimum scale division. **Write down** this smallest scale value.

Results/analysis

Make suitable measurements of the way the current in the circuit is affected for different materials. Record these measurements in a table.

Present the data in a suitable way so that you can find a relationship between the potential difference (V) and the current (I).

Conclusion

Identify a relationship in your data. **State** the relationship.

Now **share** your results with the class and **compare** to the results for other groups. What was similar about the results? What was different about the results?

Evaluate the hypothesis you made now that you have results.

Evaluation

Review your results. **Comment** on the following:

- **How consistent are they? Do they all fall close to the expected relationship or are they 'scattered' around it?**
- **Was there an intercept on your graph? Is this to be expected or is it an error?**
- **How significant (important) was the minimum scale division to the error in your results? Were there other sources of error?**
- **What could you do to minimize these sources of error?**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion C: Processing and evaluating.

When a material exhibits a linear relationship between p.d. (V) and current (I), it is said to be **ohmic** (after the German physicist Georg Ohm). Not all materials are ohmic, but metals usually are. For ohmic conductors, the relationship between V and I is directly proportional, but the actual amount of current flowing for each volt of p.d. will depend on the conductive properties of the material. The proportionality is called the resistance (R) of the material, where

$$V = IR$$

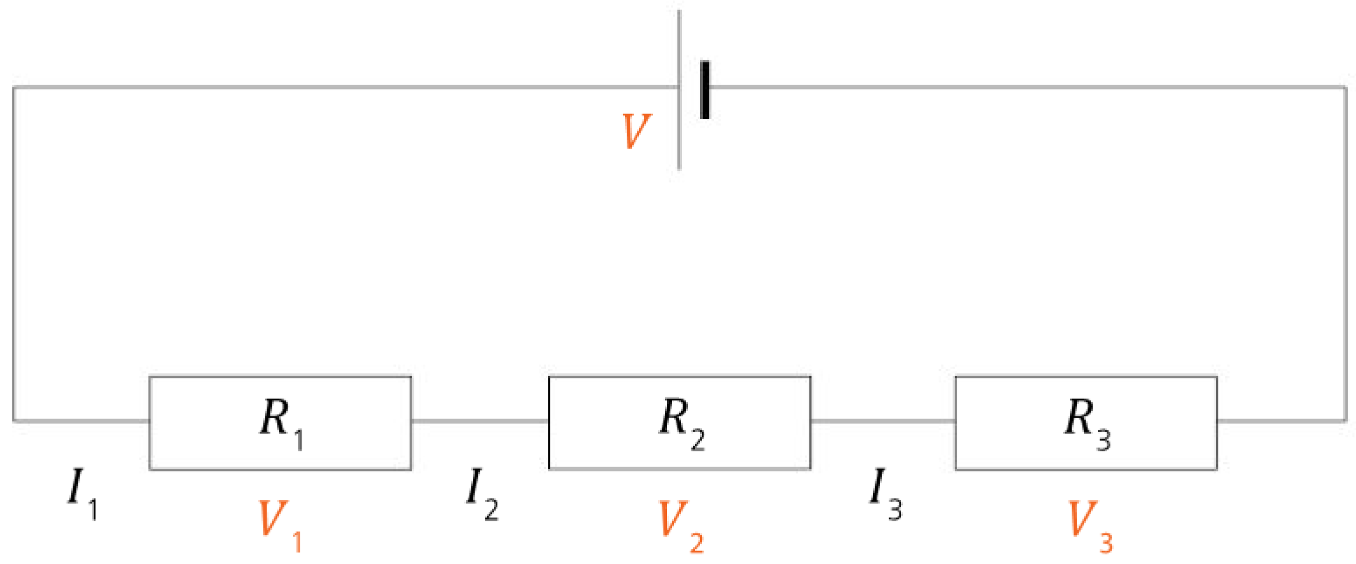
Resistance is measured in **ohms**, which have the Greek symbol omega, Ω. The relationship described above is called **Ohm's law**.

Table 8.2 shows the **resistivity** of some common materials. Resistivity is the resistance of a material for a unit area per unit length; in other words, for a fixed size of material.

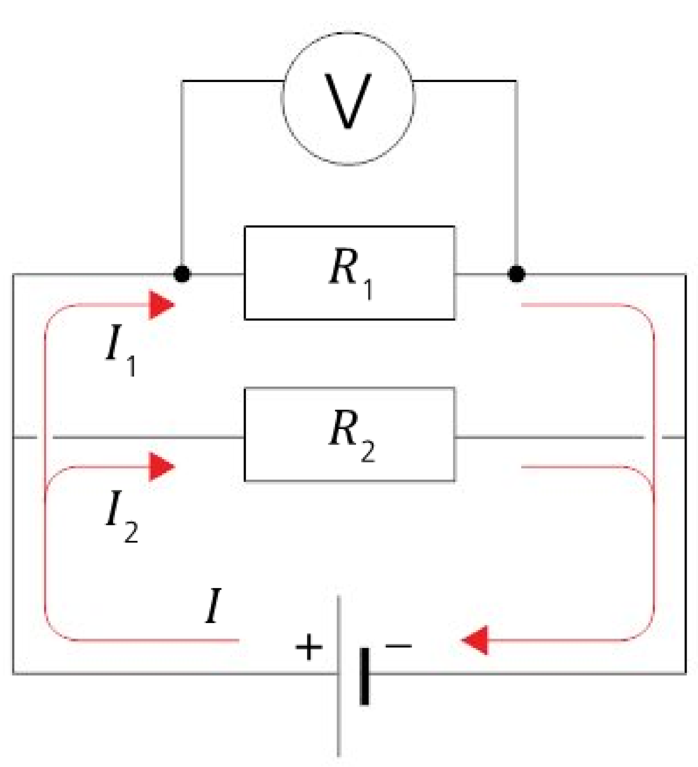
Material	Typical average resistivity/ohm.m
gold	2.21×10^{-8}
copper	1.71×10^{-8}
iron	9.71×10^{-8}
silicon	30.0
glass (Pyrex)	4×10^{5}
rubber	1.00×10^{15}
water (distilled)	1.80×10^{5}
water (fresh, tap water)	2.00×10^{2}
water (salty seawater)	2.00×10^{-1}

■ **Table 8.2** Typical resistivity of common materials

Resistance causes energy to be lost in a conductor in the form of heat. This is why resistance results in a potential difference. Resistance can be a problem, as we will find out in the next section, however it can also be a very useful thing. Carefully controlling resistance in a circuit enables us to control the p.d. and the current. Circuit components called **resistors** are engineered precisely to a known resistance, with a certain percentage uncertainty.



■ **Figure 8.24** Potential difference summing over series resistors



■ **Figure 8.25** Current splitting across parallel resistors

ACTIVITY: Resist, resist!

ATL

- Affective skills: Demonstrate persistence and perseverance

How do resistors help us to control circuit p.d. and current?

We have already explored series and parallel circuits. How do resistors behave in these combinations?

Inquiry: To measure the effect of resistors in circuit combinations

Method

Build the circuits in Figures 8.26 and 8.27 using fixed resistors.

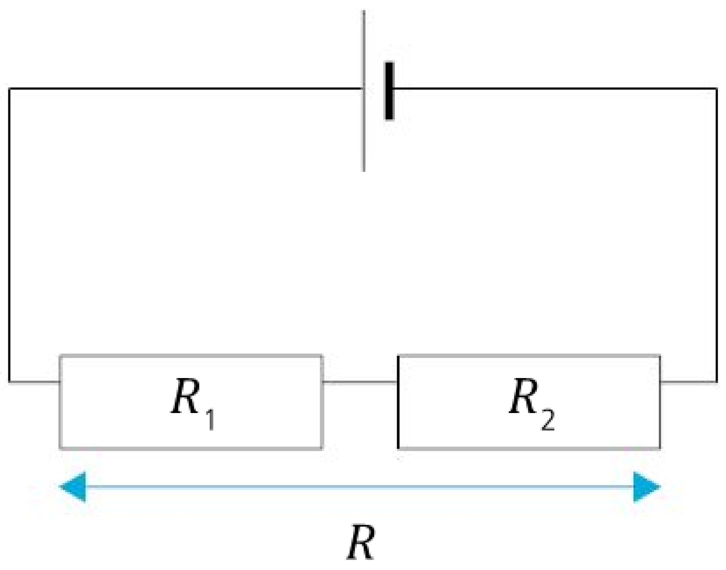


Figure 8.26 Series resistors

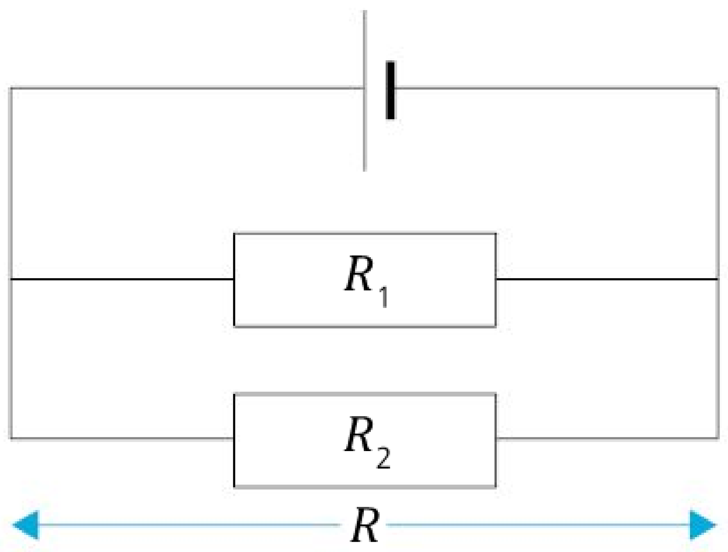


Figure 8.27 Parallel resistors

Hypothesis

What do you expect to be the total resistance of the combinations shown as R here? Which resistor network will result in the highest total resistance? **State** your hypothesis for each resistor network and then **justify** with scientific reasoning about currents, potentials and resistances.

Now use a resistance meter to **measure** the total resistance of each combination.

Conclusion

Was your hypothesis correct? If not, read on and then return to your explanation to **reflect** on what you misunderstood.

After you have learnt more, write a new conclusion that improves on the explanation you gave for your hypothesis.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion B: Inquiring and designing.

Figure 8.28 Commercial resistors.

Worked example

We can understand how resistor networks behave by analysing the way p.d. and current work in the circuits.

When in series, we need to remember that each resistor causes energy to be lost. The energy is measured as p.d., but the total amount of current flowing remains the same because we don't actually lose any electrons in the resistor. So the resistors in series each cause a p.d., but the current through all resistors is the same (Figure 8.24).

The total p.d. over all the resistors in series is given by

$$V = V_1 + V_2 + V_3 + \dots$$

and so on. Since $V = IR$ then, $IR = IR_1 + IR_2 + IR_3 + \dots$

All the currents, I, are the same here so they can be cancelled to leave

$$R = R_1 + R_2 + R_3 \dots + R_n$$

In the parallel circuit (Figure 8.25), on the other hand, the current is splitting up to flow through each of the resistors in the network, so

$$I = I_1 + I_2 + I_3 + \dots$$

However the p.d. across *each* resistor must be the same, since they are all connected between the same two points X and Y. From Ohm's law,

$$I = \frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \dots$$

Since V is the same across all resistors, it again cancels to give

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \dots \frac{1}{R_n}$$

What is the electrical circuitry of the human body?

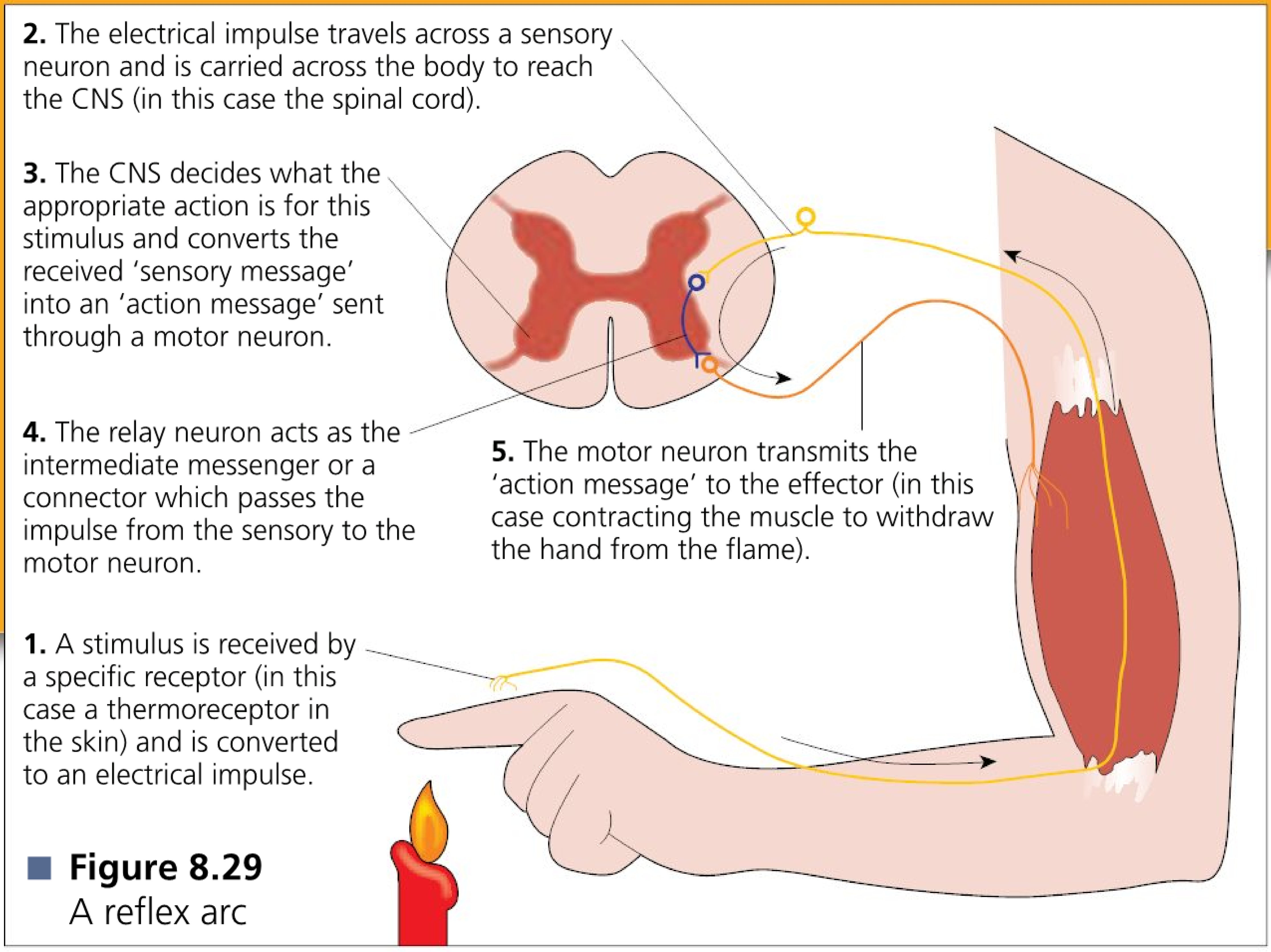


Figure 8.29 A reflex arc

CONNECT WITH YOUR SENSES

Your body has many systems that work harmoniously together like a symphony, coordinated by two coordination and communication systems. The endocrine system consists of **glands** which release hormones to control some bodily functions and send communications. The nervous system is the mastermind of your body that ensures smooth communication between your organ systems and the environment. We have survived as a human species because we learnt how to sense danger from our surroundings and act or run away from it. Our 'fight or flight' responses have saved us throughout the evolutionary history of our species. But how do we know there is danger? And how do we know how to act to escape?

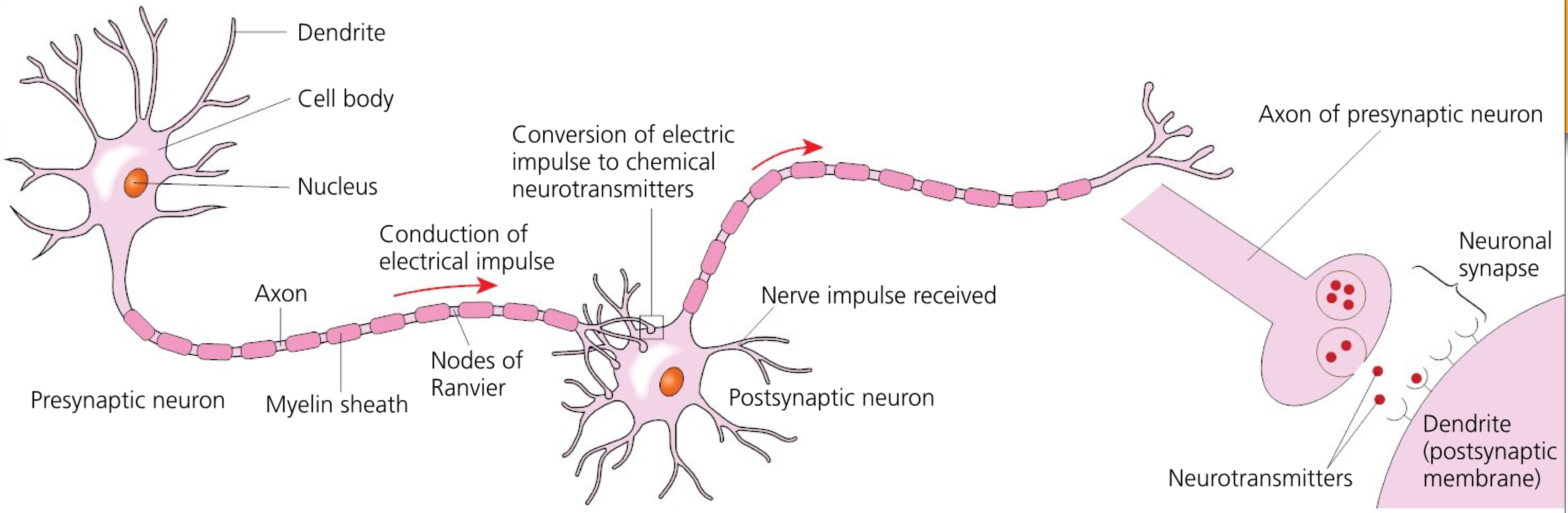
Think of a situation where your friend needs help. If you didn't know they needed you, you wouldn't act, but if they communicated with you and asked for help you would act. The same happens in your body. Many things happen around you but are they all worth reacting to? Would you react to the noise from a passing car or to the chirping of birds? Would you react if someone was trying to drench you with water or poke you in the eye?

Your **sensory organs** collect information and send it to the central nervous system (CNS) (consisting of the brain and spinal cord) which reacts by sending appropriate reaction messages to different **effectors** in your body (like muscles) which will complete the reaction instructions. Each sensory organ is specialized and adapted to sense specific **stimuli** around us.

FROM MESSAGE TO ACTION …

A stimulus turns into a message then into action. A **reflex arc** is any neural pathway that controls a simple stimulus response. The initial message received by the receptors of the sensory organ will get 'coded' as an **electrical impulse** and sent to other parts in the body to be converted into action. This happens through neurons, which are adapted to receive and transmit the electrical impulse. Each component in the stimulus response has a specific role to ensure the execution of the response.

The shape of a neuron is adapted to carry electrical impulses and then transfer them to another neuron. Transmission of the electrical impulse is achieved by different ions including sodium (Na^+) and potassium (K^+), which are exchanged between the inside and the outside of the neuron. This exchange of ions changes the voltage and the charge of the **axon**, initiating the impulse to 'jump' from one point to another. An impulse first arrives at the reception part of the neuron – the **dendrites –** then travels across the cell body and the axon responsible for conduction. When it reaches the axon terminal for transmission, the electrical impulse needs to be passed on to another neuron. Since there are no conduction parts between two neurons, the electrical impulse be converted to a chemical message, secreted in the form of **neurotransmitters** into the **synaptic cleft**, which is a space between the opposite ends of a sending neuron (the **presynaptic neuron**) and a receiving neuron (the **postsynaptic neuron**). Once the message reaches the postsynaptic neuron, it is transformed back into an electrical impulse and is carried once more through this neuron and so on until it reaches its final destination (whether the CNS for a sensory neuron or the effector for a motor neuron).



■ **Figure 8.30** Carrying and transferring a nerve impulse

ACTIVITY: What is your reaction time?

ATL

- Information literacy skills: Collect, record and verify data; Process data and report results

The nervous system reacts extremely fast to stimuli: a nerve impulse travels between 80 and 120 metres per second! Can you measure your own reaction time and see how fast you can react?

Use the following online simulations to collect data and collate your classmates' simulation results. **Plot** graphs for each activity. After your analysis, **calculate** who has the fastest reaction time. Do the same people have faster reaction times for all simulations or are there variations? Consider the different skills needed for each simulation and include this in your analysis. For example, if the brain needs to complete more complex tasks, does it need more time? Is this the same for everyone? (The simulations require Java.)

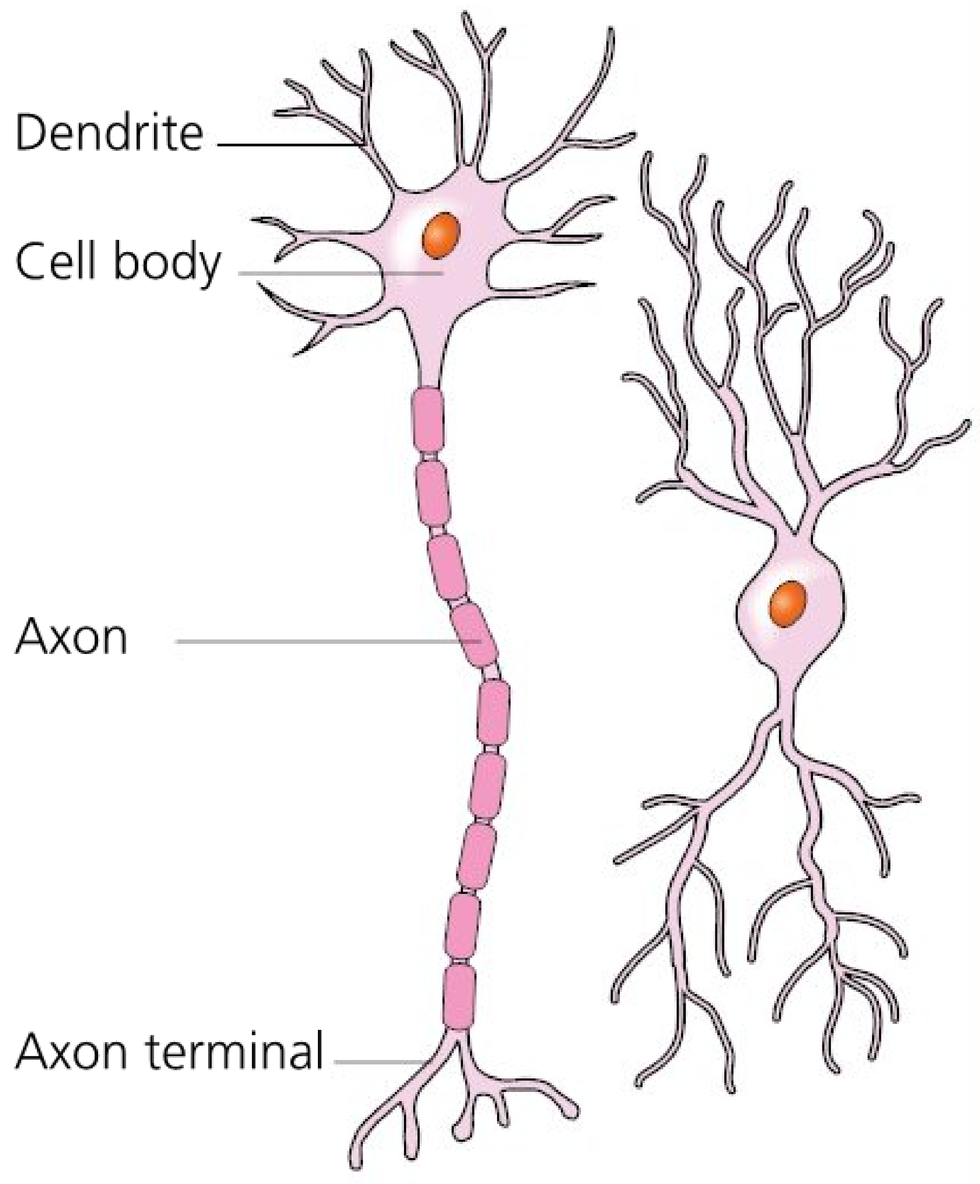
- **Simulation 1:** **https://faculty.washington.edu/chudler/java/reacttime.html**
- **Simulation 2:** **https://faculty.washington.edu/chudler/java/dottime.html**
- **Simulation 3:** **https://faculty.washington.edu/chudler/java/backtime.html**
- **Simulation 4:** **https://faculty.washington.edu/chudler/java/boxes.html**
- **Simulation 5:** **https://faculty.washington.edu/chudler/java/redgreen.html**

Assessment opportunities

- This activity can be assessed using Criterion C: Processing and evaluating.

WHAT MAKES YOU SAY THAT?

Sensory, relay and motor neurons each have form adaptations to allow them to complete their functions. Some functions are similar and others are specific to one type of neuron. Look at the two images and deduce – from the differences in shape – which is the motor/sensory neuron (note that these are similar in shape) and which is the relay neuron. Justify your answer. What makes you say that?



■ **Figure 8.31** Different neurons, different functions

ACTIVITY: Unravel neuron adaptations!

ATL

- Critical-thinking skills: Practise observing carefully in order to recognize problems
- Creative-thinking skills: Apply existing knowledge to generate new ideas, products or processes

Draw and **label** a copy of Figure 8.30 in your notebook, then answer the guiding questions below to help you unfold the functions and adaptations of different neuron structures. **Deduce** the functions from the form of each part. For every answer, add an **annotation** to your diagram in a box or an arrow **outlining** the functions and adaptations of the structures.

What do you notice about the direction of the impulse? Can it take either direction in the axon? The **myelin sheath** insulates the axon, giving it a boost to conduct the impulse faster (add this annotation to your diagram), but there are little gaps between myelinated parts of the axon called the **nodes of Ranvier**.

Discuss the following questions with your class or your teacher and **summarize** your answers by **annotating** your diagram further:

- **What is the purpose of the nodes of Ranvier?**
- **What's the advantage of having so many dendrites?**
- **What happens to the electrical impulse when it reaches the axon terminal?**
- **What should this structure do to complete the next stage?**
- **What adaptations should the dendrites have to receive the chemical neurotransmitters?**
- **What's the role of the ions in the axons?**
- **Why are neurons charged?**

Assessment opportunities

- This activity can be assessed using Criterion A: Knowing and understanding.

ACTIVITY: What's the role of the myelin sheath?

ATL

- Critical-thinking skills: Interpret data; Draw reasonable conclusions and generalizations
- Communication skills: Make inferences and draw conclusions

The myelin sheath is a fatty layer produced by specialized cells called **Schwann cells**. It insulates the axons and plays a role in propagating the nerve impulse along the axon. Myelinated neurons are not present in all animals. Figure 8.32 shows the conduction speed of the impulse (measured as propagation velocity) in myelinated and unmyelinated neurons.

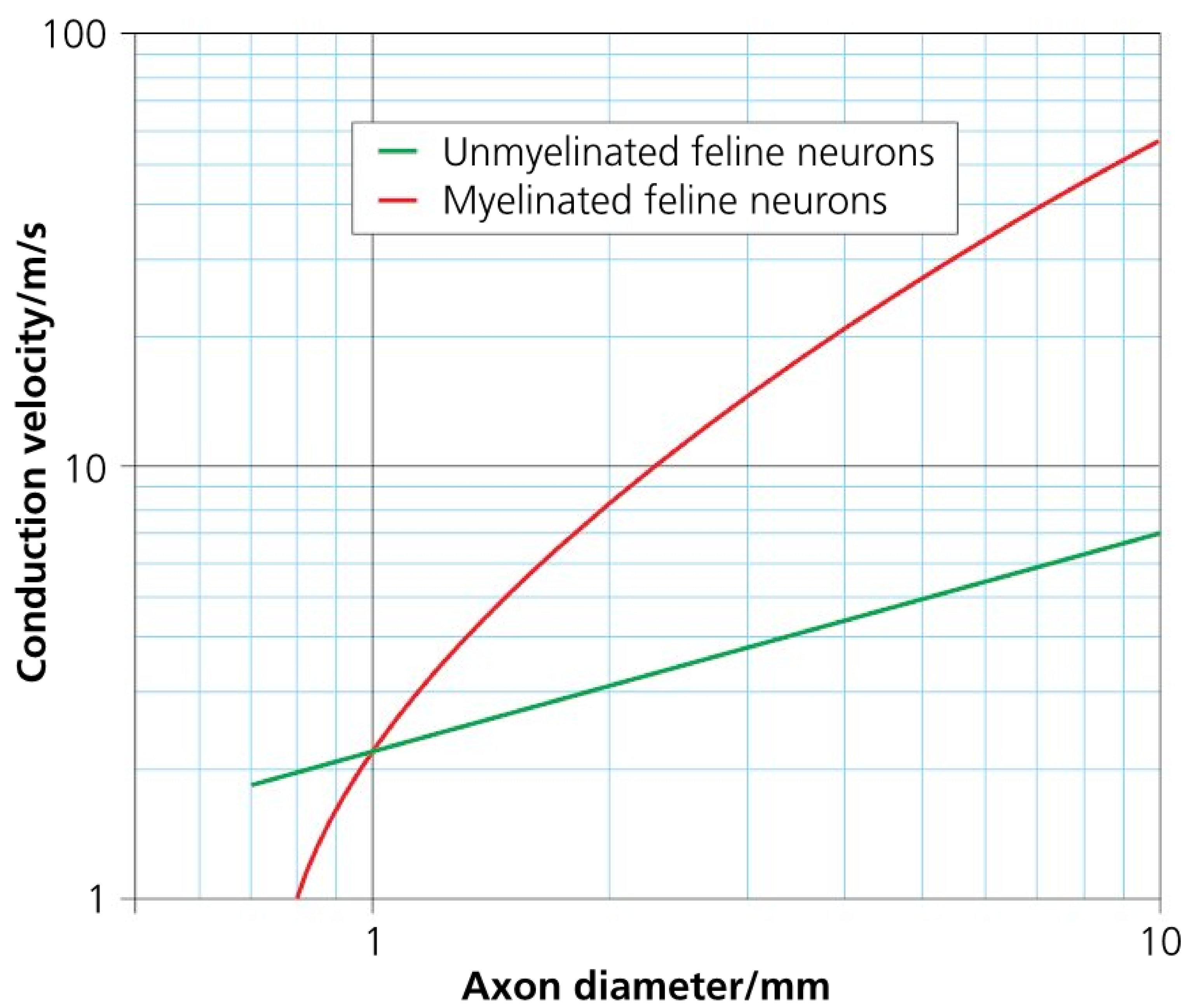
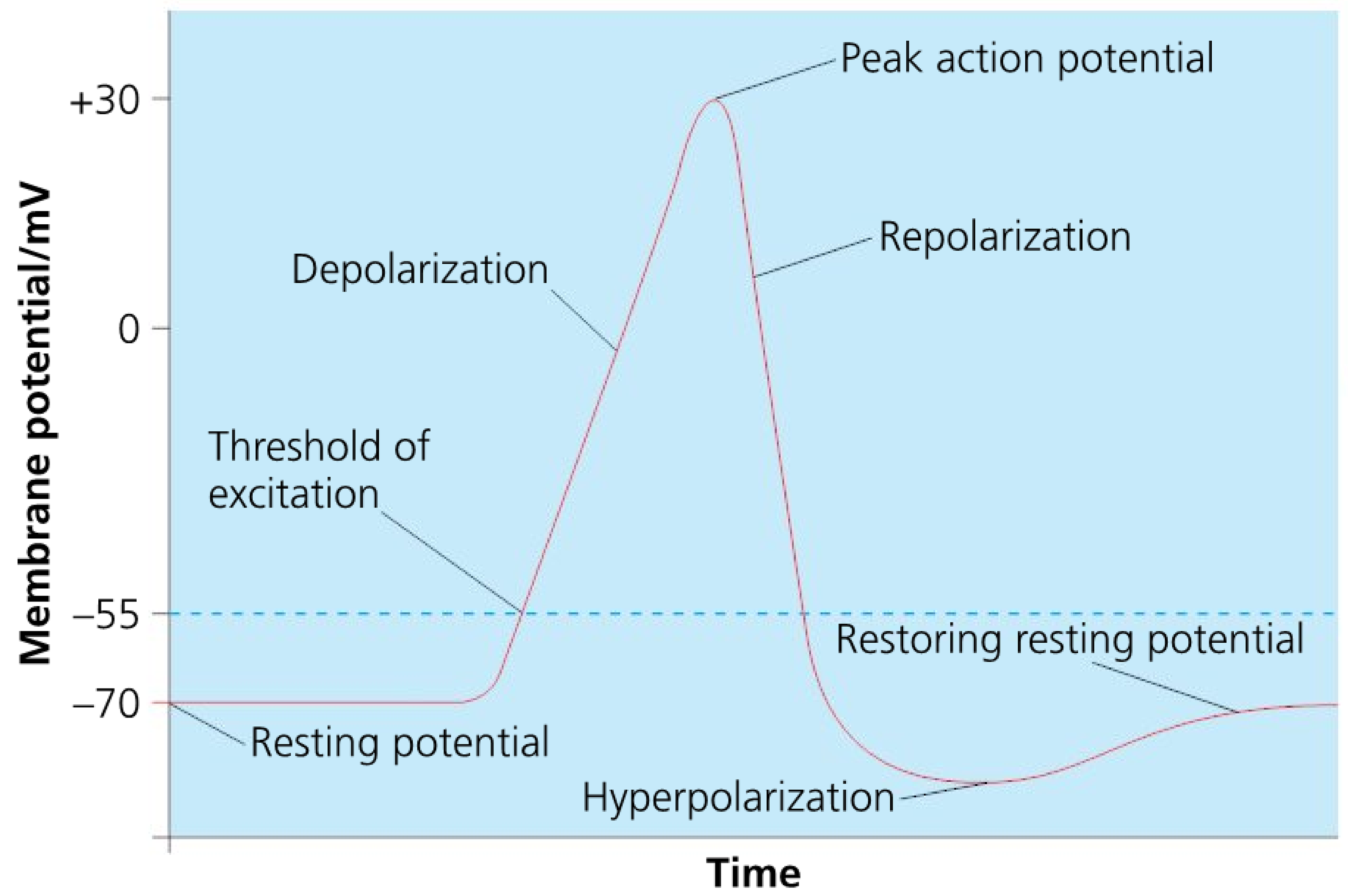


Figure 8.32 Conduction velocity of impulse in myelinated and unmyelinated neurons

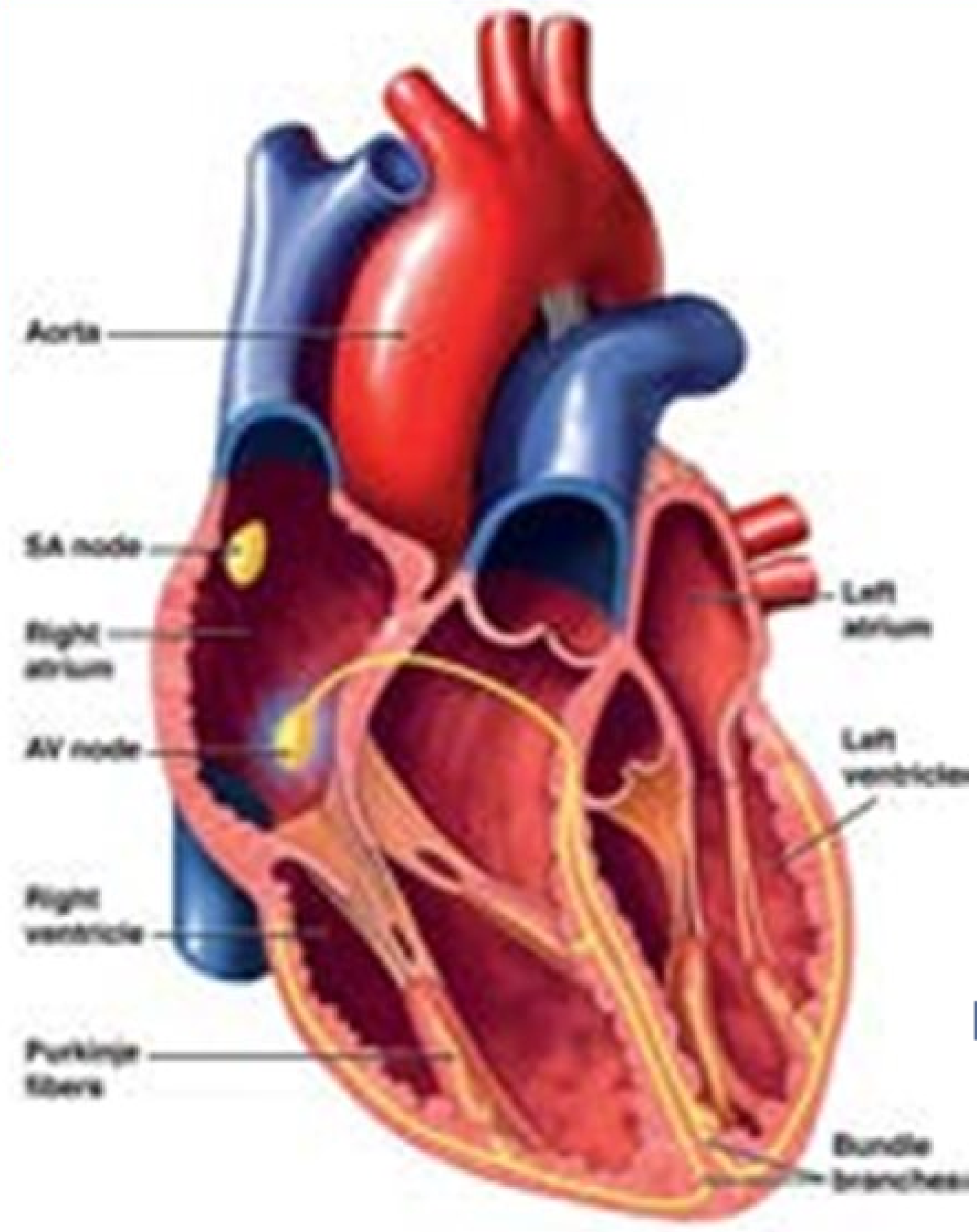
Analyse the graph and **interpret** the data. **Deduce** the relationship between the diameter of the axon and the conduction speed for both myelinated and unmyelinated neurons, and **compare** the conduction speed between these two types of neurons. Support your arguments with data from the graphs and finally **deduce** the role of the myelin sheath.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion C: Processing and evaluating.



■ **Figure 8.33** Resting and action potential during a nerve impulse



■ **Figure 8.34** The cardiac conduction system

When at rest, the neuron is polarized. It's electric potential difference is around –70 mV; this is called **resting potential**. When the electrical impulse arrives, it causes **depolarization** by disturbing the balance of the Na^+ and K^+ ions changing the potential difference to around +40 mV. But as the impulse travels along the axon, the direction of ion exchange switches again in the initial depolarized point, resetting the initial polarization state of the neuron in a phase known as **repolarization**. The consequent movement of Na^+ and K^+ ions causes a state of **hyperpolarization** where the inside of the neuron becomes *more negative* than it should be. These steps are called the action potential. This hyperpolarization quickly gets rectified by the Na^+ and K^+ ions by moving as they did before the impulse, restoring the resting potential. This resting/action potential will occur at each point of the axon as the impulse travels until it reaches the synapse, at which point it will be transmitted to the next neuron in the form of neurotransmitters. The myelin sheath insulates the axon and the nodes of Ranvier give the current a boost and facilitate the rapid conduction of nerve impulses.

YOUR ELECTRIC HEART

Your brain is not the only organ that works with electricity: your heart rhythm is also regulated by an electric current created by the body. The **sinoatrial node** (SA node) – also called the **natural pacemaker** – is located above the **right atrium** in the heart. It generates electrical impulses and propagates them through the heart muscle to promote contraction of the heart and so pumping of the blood. The impulse then travels across other heart muscle cells through the **bundle of His** and the **Purkinje fibres**. Contractions of the heart muscle are considered **myogenic** since they originate from the heart tissue itself and don't require nerve stimulation. When the SA node sends the impulse, the atria and ventricles contract and relax, pumping the deoxygenated blood received from the body to the lungs through the **pulmonary artery**, and distributing oxygenated blood received from the lungs into the body through the **aorta**.

There are some conditions known as **arrhythmia** where the heart rhythm is irregular. This can be diagnosed from an **electrocardiogram (ECG)**, by checking the electric activity of the heart.

ACTIVITY: A heart workout!

ATL

- Information literacy skills: Collect, record and verify data; Process data and report results

See how exercise affects your heart rhythm shown by the change in your heartbeat. **Design** an investigation to compare the heartbeat of you and your classmates before and after exercise. **Define** your dependent and independent variables. What will you change in this investigation and what will be measured? Use the MYP *Sciences Inquiry Cycle* from Chapter 1 to design and carry out your investigation, gather data, **analyse** and **evaluate** it.

Assessment opportunities

- This activity can be assessed using Criterion B: Inquiring and designing and Criterion C: Processing and evaluating.

How do electrical systems enhance our ability to express ourselves?

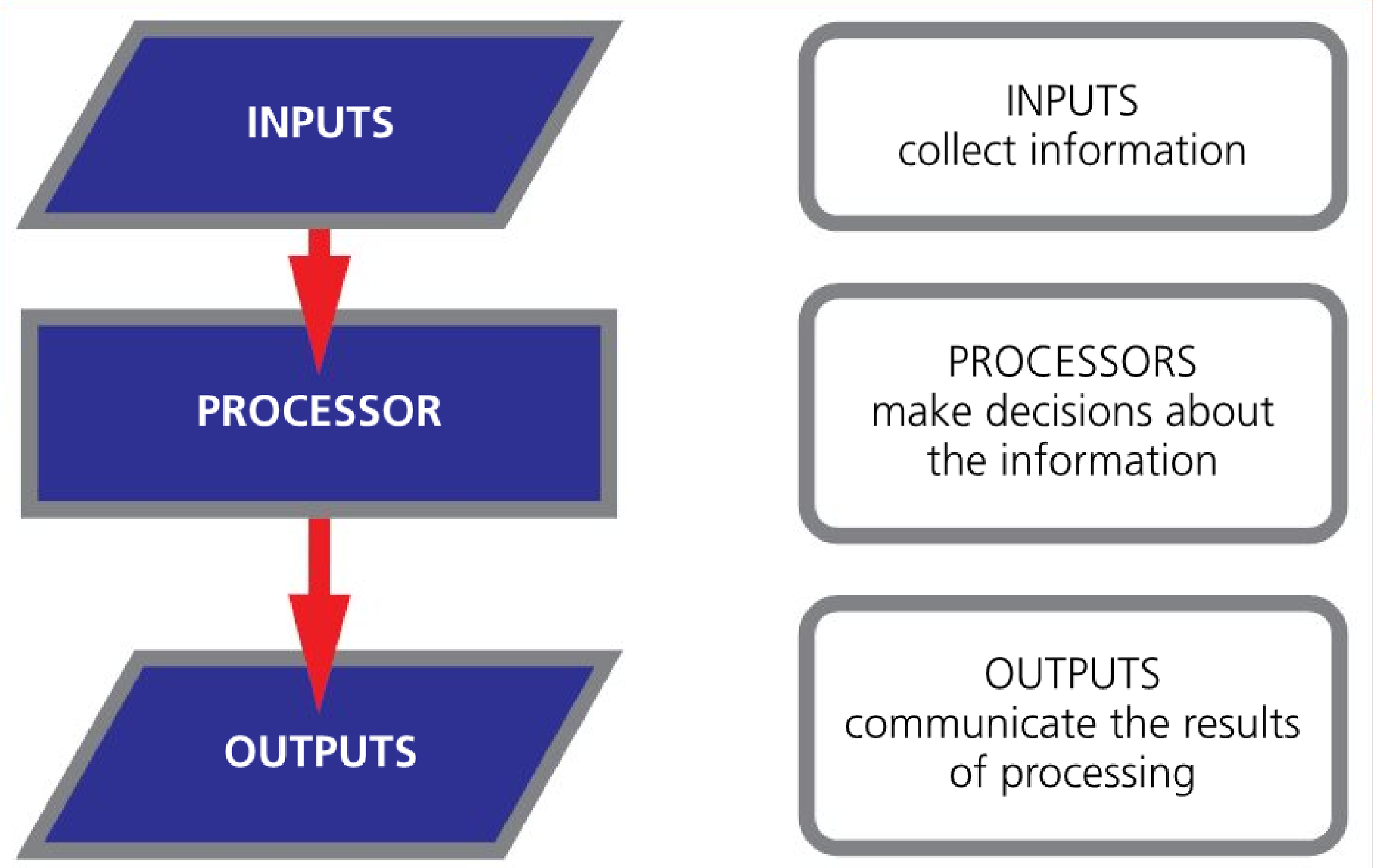


Figure 8.35

ACTIVITY: Electronic senses

ATL

- Critical-thinking skills: Consider ideas from multiple perspectives
- Creative-thinking skills: Make unexpected or unusual connections between objects

Figure 8.35 shows the three basic components of any digital electronic system in the form of a **flow chart**. A flow chart is a schematic showing the way that a system processes information.

Analyse the diagram and **interpret** the information in order to **classify** the parts of a biological system. Copy and complete Table 8.3 showing the parallels between electronic devices and biological systems.

Part of system	Digital device	Biological system
inputs	light sensor temperature sensor keyboard microphone …	
processor	central processing unit (CPU)	
outputs	screen speakers	

Table 8.3 Comparing electronic and biological systems

Evaluate your classification of the devices and systems. Do any fall into more than one category?

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

How do you express yourself? While our direct interactions might rely on the operation of our nervous system and musculature, increasingly we are communicating and expressing ourselves through electronic media, creating and managing 'virtual' selves. In *MYP Sciences by Concept 3:* Chapter 5 we looked at some of the systems that enable our virtual worlds, such as the world wide web. We also considered the importance of maintaining a clear dividing line between our virtual and real lives, by being smart and staying safe on the internet. You may already know, therefore, how the technologies that enable the virtual world rely on **digital electronics**. In order to interact with us, these machines require their own senses, their own 'minds' and their own communication systems.

MACHINE SENSES

Senses help living things respond to environmental conditions. Three important such senses are sensitivity to light, temperature and sound. How do electronic devices sense these?

A **microphone** is a device for detecting sound. There are different kinds of microphone, some of which work using electromagnetic systems and others which use special pressure-sensitive piezoelectric materials. Since sound is transmitted through a medium as a wave, the output from a microphone is an AC that has the same shape and frequency as the detected wave (although the amplitude

ACTIVITY: Sensing electronically

ATL

- Critical-thinking skills: Interpret data

Individually or in pairs, you will use a multimeter to **measure** the response of two different sensors, a LDR or a thermistor.

Multimeters allow us to measure various electrical properties directly. You will need a multimeter that measures resistance with different scales. Look carefully at the dial on the multimeter and **identify** the settings for different resistance scales: these will typically be 0.1 Ω, 10 Ω, 1 kΩ, 100 MΩ or similar. The meter will read the resistance of anything placed between the probes.

Equipment

- **Multimeter**
- **Electronic sensor: LDR or thermistor**

Method

Design your own method for measuring the response of the sensor to changing conditions.

Safety: Ensure your teacher checks your design for safety, especially if you plan to use high temperatures.

Predict whether the results will be linear. Will they be negatively or positively correlated? **Explain** in terms of the science of electricity and your own research into these components.

Collect data and **record** it clearly, showing units of measurement and any measurement uncertainties. **Organize** your data and **present** it in a graph to **interpret** the relationship between variables. **Summarize** your findings in a conclusion. Was your hypothesis valid? **Describe** any unexpected results and try to **explain** why they may have occurred.

Evaluate your method. Was it valid? Was it reliable? **Suggest** any improvements you could have made to reduce uncertainty or to address any of the unexpected results you found.

Assessment opportunities

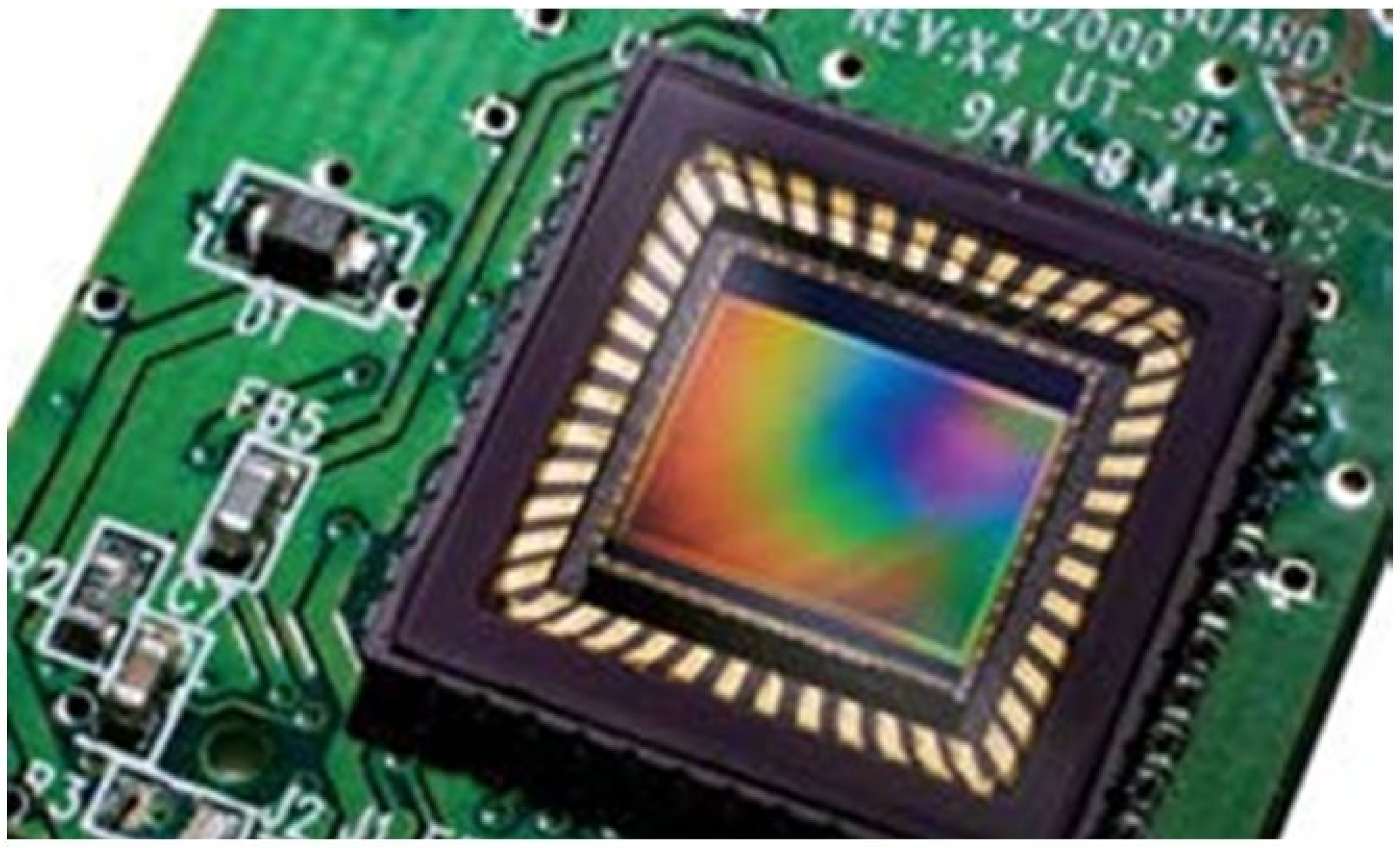
- In this activity you have practised skills that are assessed using Criterion B: Inquiring and designing and Criterion C: Processing and evaluating.

will be different, as the output will be produced as a varying p.d. and current).

Light sensors also come in different types, although all 'express' information on light intensity through a change in their resistance. Examples of light sensors are light-dependent resistors (LDRs) and photodiodes.

Temperature sensors also express information about temperature through a variation in resistance. Examples of temperature sensors are thermistors, thermocouples and temperature-sensitive diodes.

The detection of complex images in devices such as digital cameras is achieved using **charge-coupled devices** (**CCDs**). Instead of light-dependent resistors, CCDs use a matrix of light-sensitive semiconductor devices whose ability to store charge varies when **photons** of light fall on them. Information about an image is then encoded digitally (in binary: see *MYP Sciences by Concept 3:* Chapter 5). Consequently, the quality of the image recorded depends on the number of light-sensitive points on the CCD – its **resolution**.

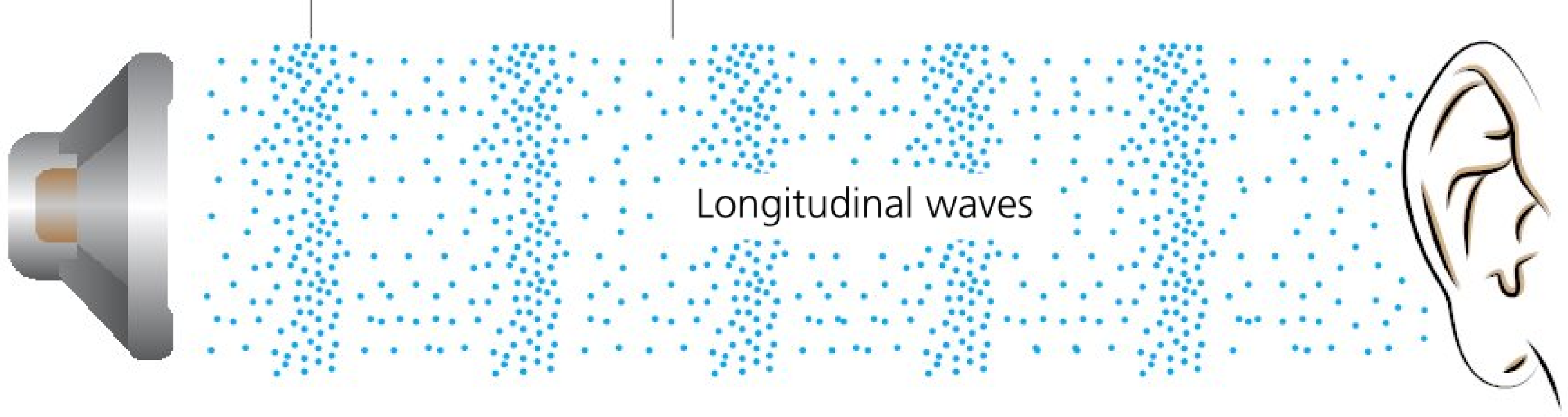


■ **Figure 8.36** Digital cameras detect images using CCDs

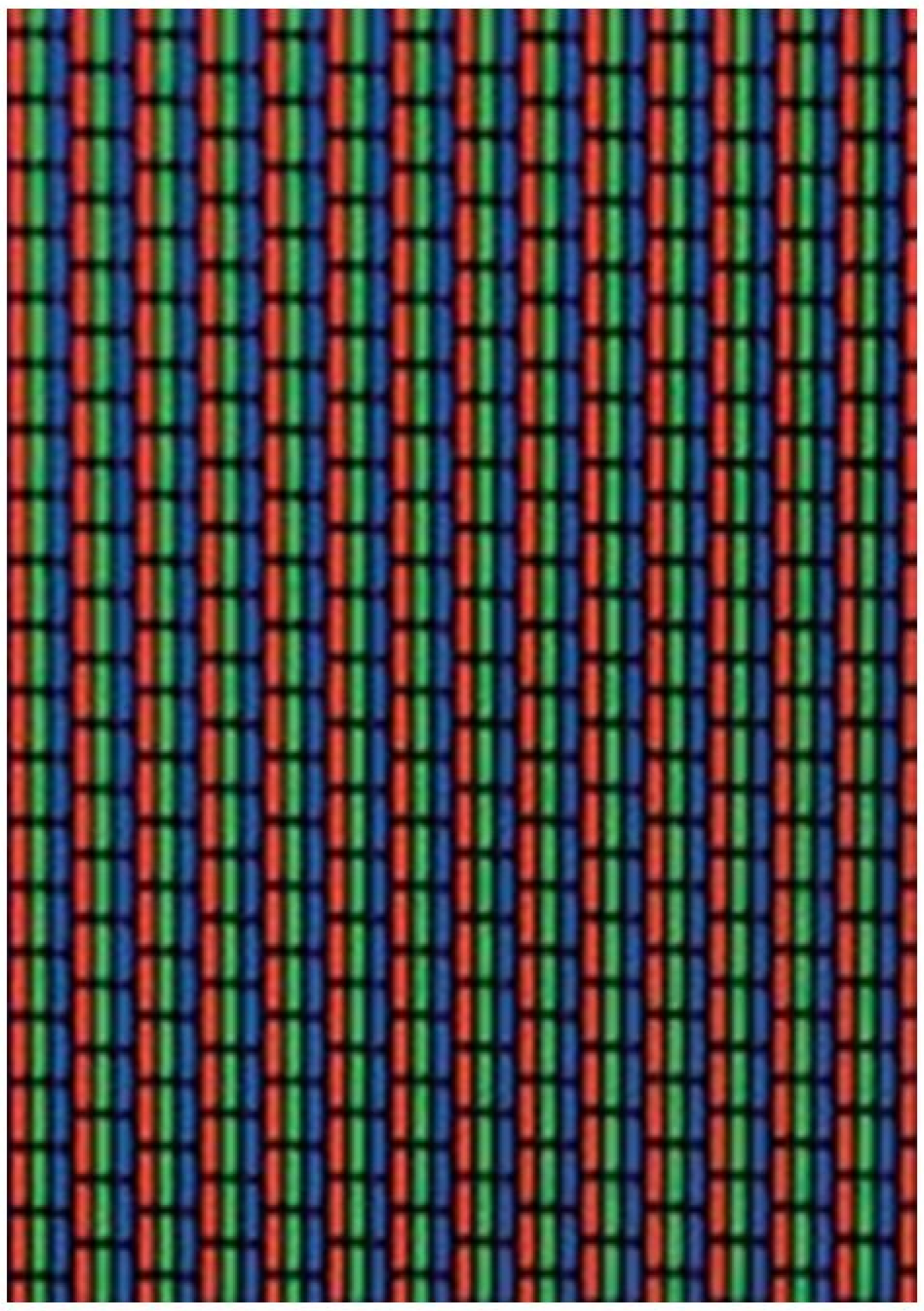
To what extent does our understanding of electricity improve our lives?

MACHINE COMMUNICATIONS

Once processed, the information received by a machine must be communicated back to we humans, the operators, in a form we can understand. **Loudspeakers** produce sounds by moving a membrane with an electromagnet. An AC passing through the electromagnet causes the membrane to move, so producing a sound wave that mimics the shape and frequency of the signal (see *MYP Sciences by Concept 3:* Chapter 5 and *MYP Physics by Concept 4&5:* Chapter 7). Loudspeakers are typically used now only for large-amplitude (high-volume) sound. For handheld devices, such as smartphones and headphones, piezoelectric materials are used to produce the same effect; when a current passes through the piezoelectric material, it produces a physical vibration.



■ **Figure 8.37** Loudspeakers create sound waves using vibrations produced by an electromagnetic coil or a piezoelectric material



■ **Figure 8.38** The full-colour image produced by a digital screen requires many millions of individual illuminated pixels, mixing the colours from three pixels for each point

To reproduce visible images, a digital screen must represent the image information as many tiny points of light called **pixels**. Each pixel has variable brightness according to the p.d. used to 'activate' it. In order to produce a colour image, three pixels are used for every single point on the screen; typically one red, one blue and one green (see *MYP Sciences by Concept 2:* Chapter 4 for more detail).

! Take action: Bacteria that eat pollution and generate electricity

ATL

- Critical-thinking skills: Analyse complex concepts and projects into their constituent parts and synthesize them to create new understanding; Gather and organize relevant information to formulate an argument; Evaluate evidence and arguments; Draw reasonable conclusions and generalizations
- Creative-thinking skills: Create original works and ideas; Use existing works and ideas in new ways

! You are a young scientist working in a research laboratory focusing on microbial electrogenesis and bioengineering. Your research explores ways to harness and exploit electricity-producing organisms as efficient, cost-effective and environment-friendly electricity generators. You want to write a literature review to **summarize** the research that has been published in various scientific articles on this topic. You should read as many articles related to your topic as you can and extract relevant information into one coherent article to be published in a scientific journal. The research is done by other scientists, so it is essential that you **document** and reference each article. Carry out your research using the websites below as starting points and these search terms: **bioelectrogenesis, microbial fuel cells, electrigens, microbial electrogenesis**.

www.researchgate.net/publication/264243712_bacteria_eating_pollution_and_generating_electricity

www.bioelectrogenesis.com/docs/Abraham_Esteve-Nunez_Intl_Innovation_181_Research_Media_04.pdf (pdf download)

www.nature.com/nrmicro/journal/v4/n7/full/nrmicro1442.html

www.nature.com/articles/srep25571

! Before scientists publish their work in scientific journals, their work is first peer reviewed by other scientists in the field. Your teacher will be the editor of the journal you are submitting your review to and, once submitted, it will be sent for peer review to other science teachers and students from other grades.

! When you have their feedback, address any clarity issues and add necessary information, then submit it again to your teacher for another revision of your manuscript. Once done, you can submit your review to an international journal that publishes work from high school students such as: **www.questioz.com/**. If your work doesn't get accepted, don't despair as this is another experience of scientists who may work for many years to get their work accepted in a scientific journal!

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

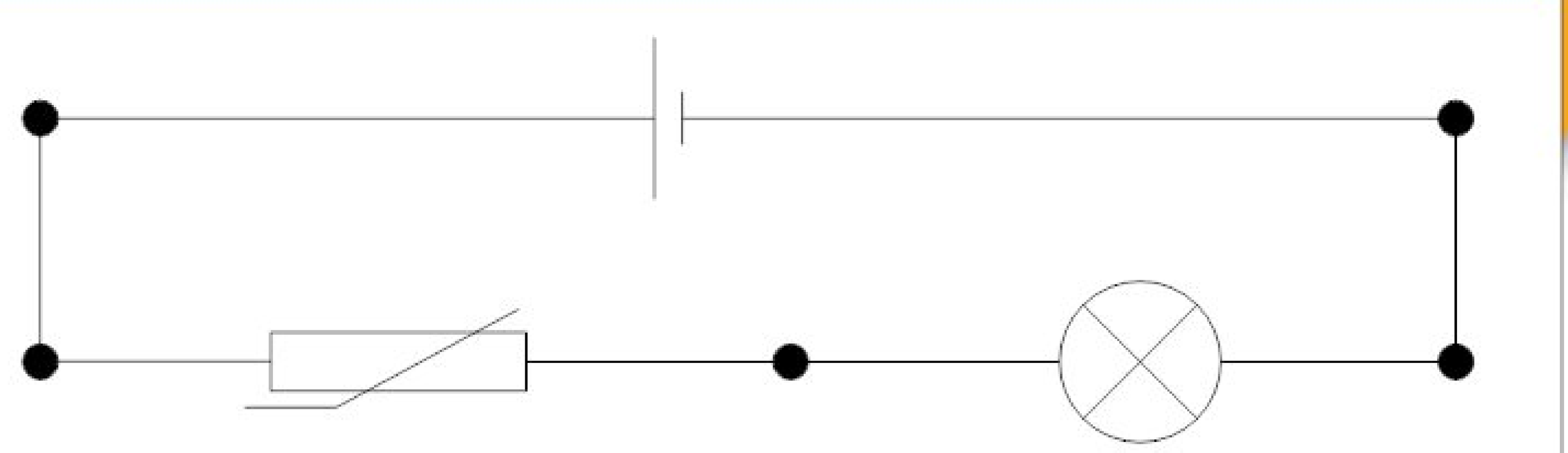


Figure 8.39

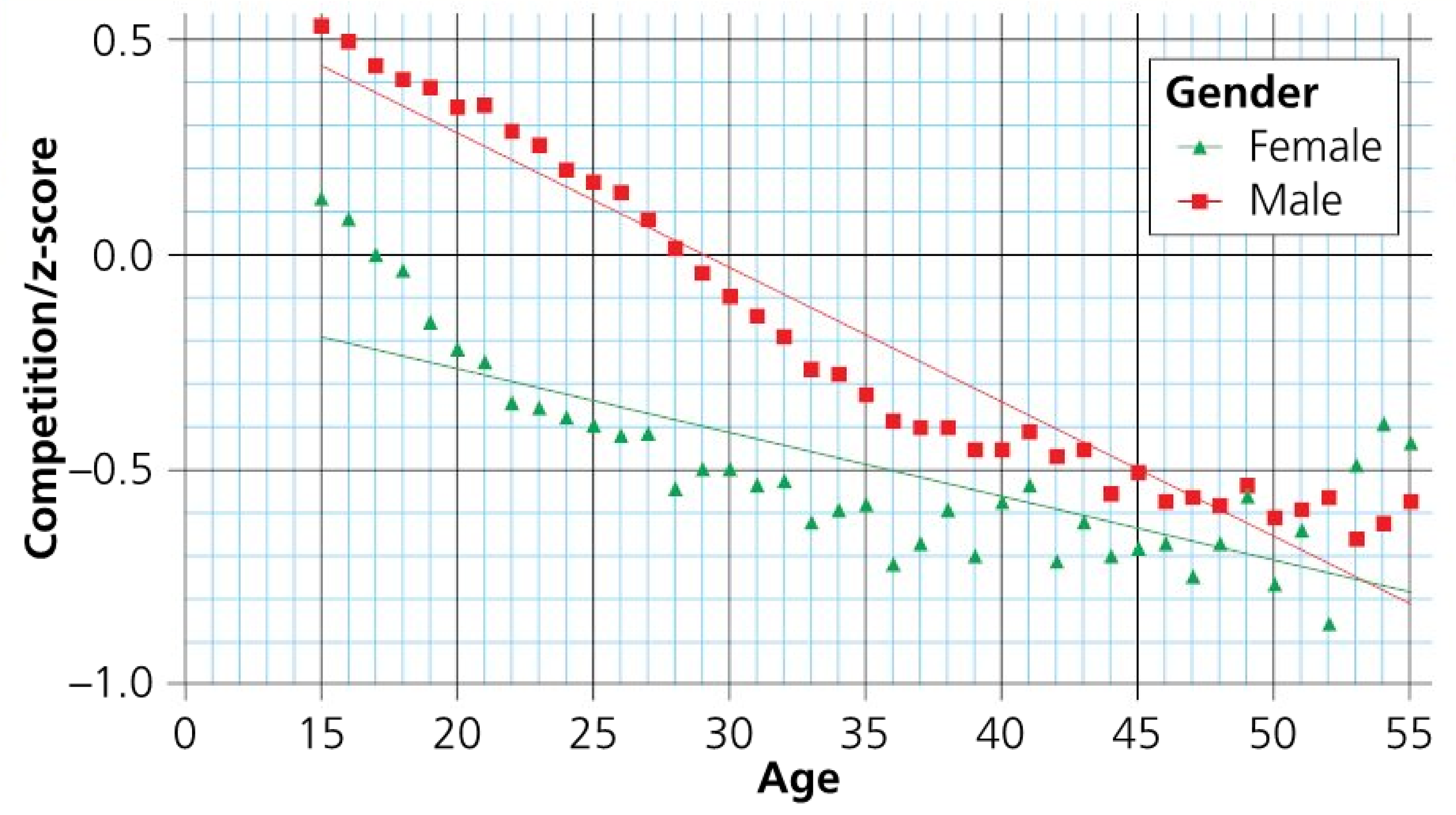


Figure 8.40 Reaction time with age

SOME REVIEW PROBLEMS TO TRY

1 a **State** the products that would be formed during the electrolysis of the following molten compounds and **state** which electrode (anode or cathode) each product will be formed at:
   i zinc sulfide
   ii magnesium oxide
   iii iron (II) chloride.
  b i **Draw** and **label** an electrolytic cell for the electrolysis of molten potassium iodide.
   ii **Formulate** balanced half-equations for the processes that occur at the anode and cathode, clearly stating which process is an oxidation and which is a reduction.
  c **Explain** why the electrolyte was molten.

2 1.5 V AA-size batteries have a charge of 2500 mA h (milliamp-hours). This means that they hold sufficient electric charge to provide a current of 2500 mA for 1 hour.
  a **State** the charge, *Q*, in coulombs stored in a AA-size battery.

  Figure 8.39 shows a circuit diagram. The circuit consists of a thermistor connected in series to a lamp. The thermistor has a negative temperature coefficient, meaning that its resistance decreases as temperature increases. Both are provided with current from a 1.5 V AA-size battery.
  b **Describe** how the properties of the thermistor will change when touched with a finger.
  c The lamp has a maximum p.d. of 1.0 V and a maximum current rating of 250 mA. **Calculate** the resistance of the bulb.
  d The thermistor has a resistance of 100 Ω at 25 °C. **Calculate** the current in the circuit at this temperature. Thus, **calculate** how long the circuit will work until the battery is discharged.
  e **Analyse** the circuit diagram and so **describe** how the brightness of the light from the lamp will change when the thermistor is warmed.

  Aleksei thinks that there is a danger that the current in the circuit could exceed the maximum current rating for the lamp, causing the lamp to blow. Monica thinks this can't happen, because the thermistor will never have zero resistance.
  f **Evaluate** Monica and Aleksei's arguments and so **state** who you think is correct. **Show** your reasoning, with calculations or otherwise.

3 Components of the nervous system transmit and convert stimuli to actions, but the rate of reaction varies depending on many factors including age.
  a **Analyse** and **evaluate** the data presented in Figure 8.40 to **deduce** the effect of age on competition. Support your answer with your knowledge of how the nervous system reacts.
  b **Compare and contrast** your analysis from part (a) to the reaction time of Sir Mo Farah (born in 1983) in his international 5000 m races over the years (Table 8.4).

Year	Competition	Position	Time
2000	World Junior Championships	10th	14:12.21
2001	European Junior Championships	1st	14:09.91
2003	European U23 Championships	2nd	13:58.88
2005	European U23 Championships	2nd	14:10.96
2006	European Athletics Championships	2nd	13:44.79
2009	World Championships	7th	13:19.69
2013	World Championships	1st	13:26.98
2016	Olympic Games	1st	13:03.30
2017	World Championships	2nd	13:33.22

Table 8.4

Reflection

In this chapter we have **outlined** different ways in which electricity can be generated by both natural and artificial means. We have **explained** the relationship between electrical charge and electric current, and we have **described** how electric current flow relates to both resistance in a circuit and to electric potential difference, using Ohm's law. We have **analysed** circuits to **predict** their function, including resistance networks.

We have **described** how electrolysis enables us to utilize electric current in a number of different ways and **described** how to set up an electrolytic cell. We have **defined** the terms reduction and oxidation in terms of electron gain or loss to enable us to **apply** them to a larger range of reactions and **described** redox reactions by learning how to **formulate** half-equations for the electrolysis of molten ionic compounds. We have **explained** how electrolysis is used in the industrial process of purification, **outlined** a number of real-life applications of redox and **reflected** on whether electrolysis can be used to generate the fuel of the future.

We have **outlined** how we communicate and respond to stimuli in our surroundings. We **described** the adaptation features in neurons which allow them to perform their function and we **justified** why certain adaptations are necessary to pass the nerve impulse successfully. We **explained** how a nervous impulse gets carried through a neuron and transferred across to another neuron. We **described** how the heart also has its own electric system and **demonstrated** how our understanding of it can be used for medical diagnosis. We **evaluated** different uses of electricity from living organisms and their potential use as electricity generators.

Finally, we **compared** natural to artificial electronic systems and **outlined** the function of different sensors, processors and output systems.

<table>
<tr><th colspan="6">Use this table to reflect on your own learning in this chapter</th></tr>
<tr><td>Questions we asked</td><td>Answers we found</td><td colspan="4">Any further questions now?</td></tr>
<tr><td>Factual</td><td></td><td colspan="4"></td></tr>
<tr><td>Conceptual</td><td></td><td colspan="4"></td></tr>
<tr><td>Debatable</td><td></td><td colspan="4"></td></tr>
<tr><td rowspan="2">Approaches to learning you used in this chapter:</td><td rowspan="2">Description – what new skills did you learn?</td><td colspan="4">How well did you master the skills?</td></tr>
<tr><td>Novice</td><td>Learner</td><td>Practitioner</td><td>Expert</td></tr>
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<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Learner profile attribute(s)</td><td colspan="5">Reflect on the importance of being a risk-taker for your learning in this chapter</td></tr>
<tr><td>Risk-takers</td><td colspan="5"></td></tr>
</table>

9 How do we pass on our inheritance?

We are formed by what we **inherit from our parents**, **transformed** by our **relationship** with the environment.

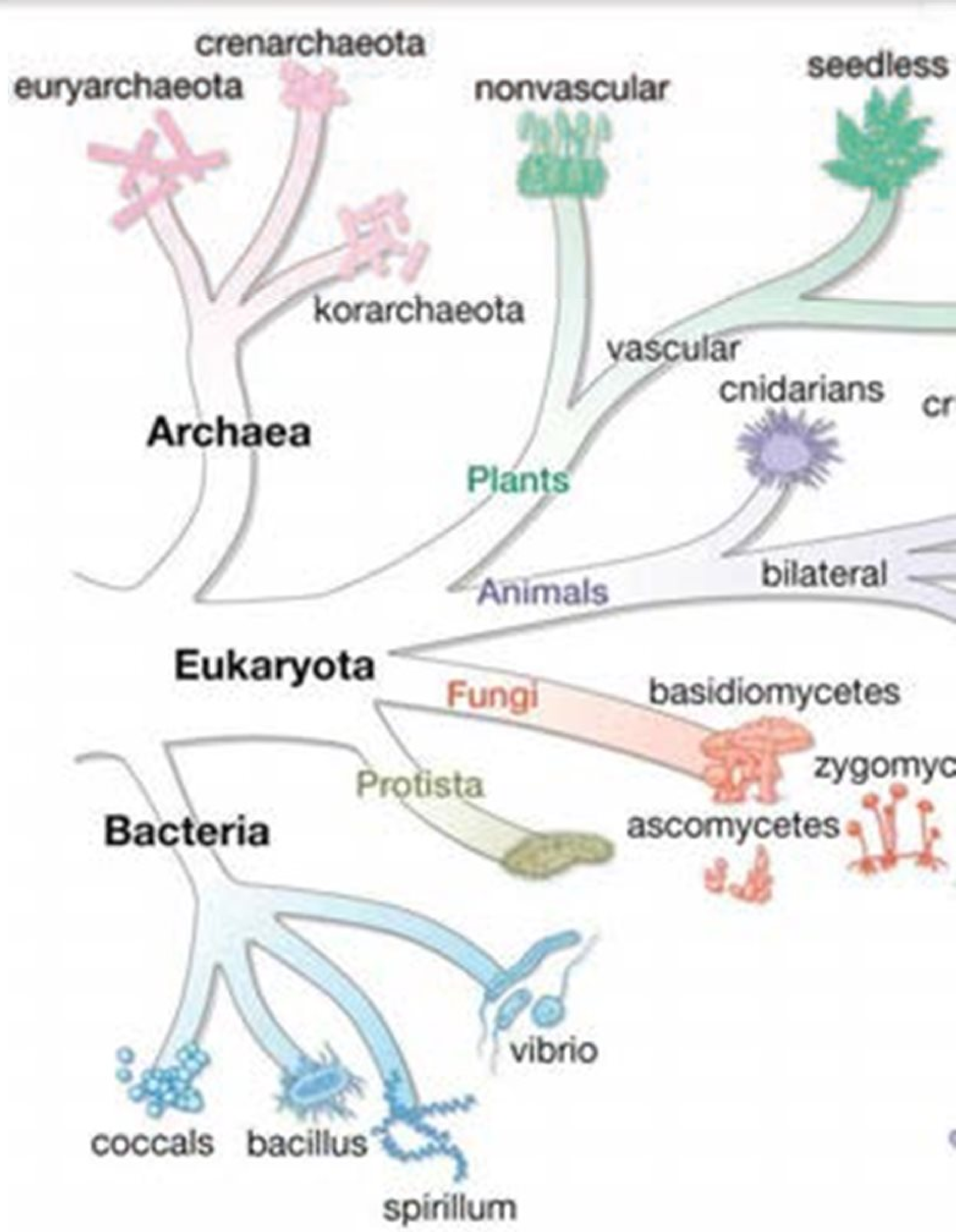


Figure 9.1 The tree of life. Where are we?

CONSIDER THESE QUESTIONS:

Factual: What's in our genes? How do organisms reproduce? What is ionizing radiation? How can we use ionizing radiations?

Conceptual: How do living things ensure their continuity? How can heredity go wrong? What determines the effect of ionizing radiations on matter?

Debatable: Should we modify the genetics of living things?

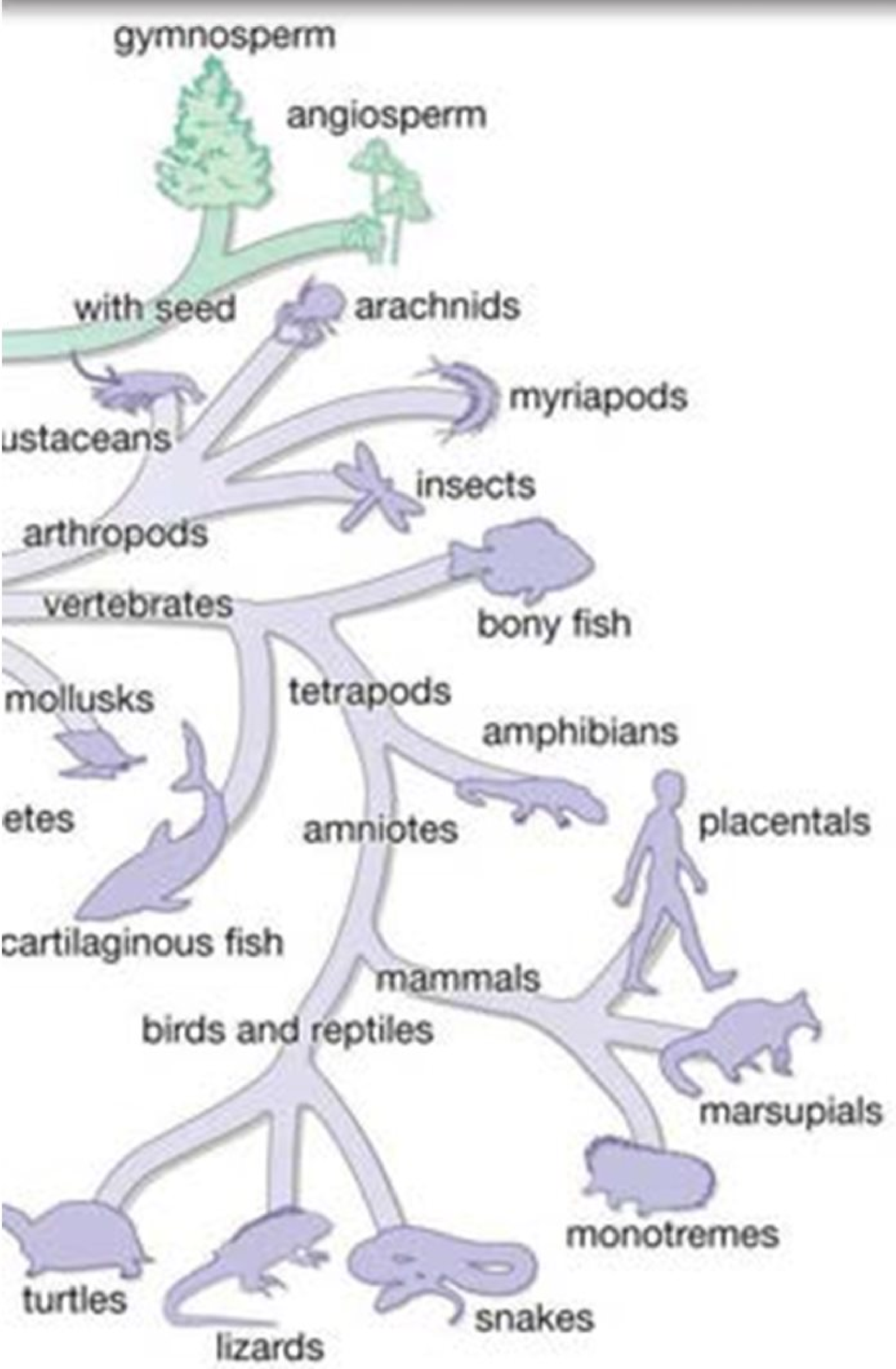
Now **share and compare** your thoughts and ideas with your partner or with the whole class.

KEY WORDS

code	inherit
complement	mate
decay	reproduce
environment	

IN THIS CHAPTER, WE WILL …

- **Find out** how life forms pass on their characteristics and how they differ.
- **Explore** the science of genetics and the processes by which cells reproduce.
- **Take action** to consider the possibilities of human-made interventions in the reproduction of living things through genetic modification.



These Approaches to Learning (ATL) skills will be useful …

- Critical-thinking skills
- Creative-thinking skills
- Information literacy skills
- Reflection skills
- Communication skills
- Organization skills
- Transfer skills
- Collaboration skills

Assessment opportunities in this chapter:

The activities in this chapter will help you develop and evaluate your learning in these MYP Sciences learning objectives:

- **Criterion A:** Knowing and understanding
- **Criterion B:** Inquiring and designing
- **Criterion C:** Processing and evaluating
- **Criterion D:** Reflecting on the impacts of science.

SEE–THINK–WONDER

Look at Figure 9.1. What do you **see**? What does it make you **think**? What does it make you **wonder**?

Earth is rich with life. We are surrounded by, and we are connected to, myriad diverse forms of life. Some forms of life are so strange and different from us that they may seem almost alien, but – as far as we know – all this life originated on our own planet. So how did this diversity come about?

We saw in Chapter 3 how scientists have sought to make sense of the 'tree of life' by **classifying** living things in terms of their observable characteristics. In this chapter we will explore further how those life forms have developed and how they pass their characteristics across the generations. We will also look at one important factor in causing change in life forms: radioactivity.

We will reflect on this learner profile attribute …

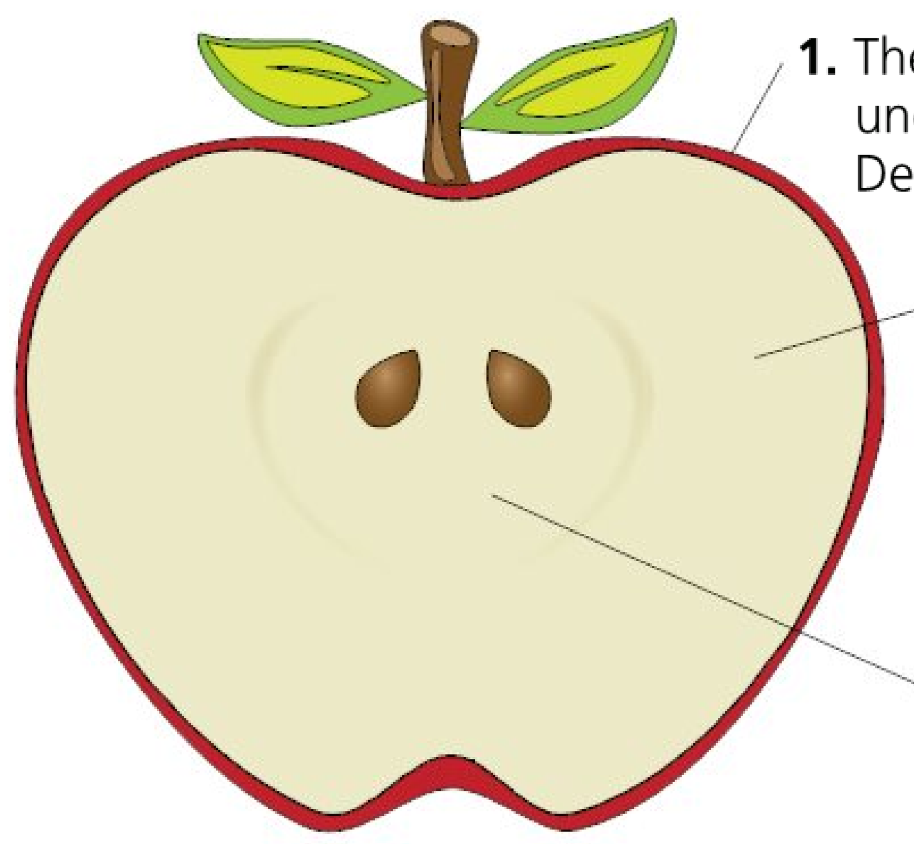
- Reflective – we will consider our place in the tree of life and what may be the consequences of seeking to control the processes of inheritance.

What's in our genes?

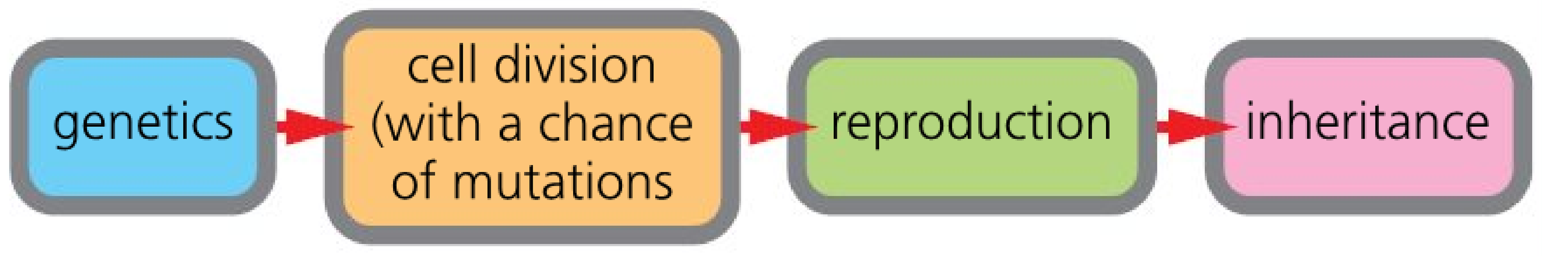
PEEL THE FRUIT!

ATL

- Critical-thinking skills: Draw reasonable conclusions and generalizations; Analyse complex concepts and projects into their constituent parts and synthesize them to create new understanding



■ **Figure 9.2** Peel the fruit



■ **Figure 9.3** Connect the concepts

In this activity you will **create** a map that will visually represent the way your conceptual understanding of the chapter develops.

Use poster paper and stick it on the wall. Draw three circles, one inside another and label the spaces from the outside to the inside: the skin, the substance, the core.

This is an 'active' map; you will refer to it throughout the chapter as you 'peel' different levels of understanding of the topic. You can use different coloured marker pens to write on each circle or preferably use different coloured sticky notes to log your understanding at different stages.

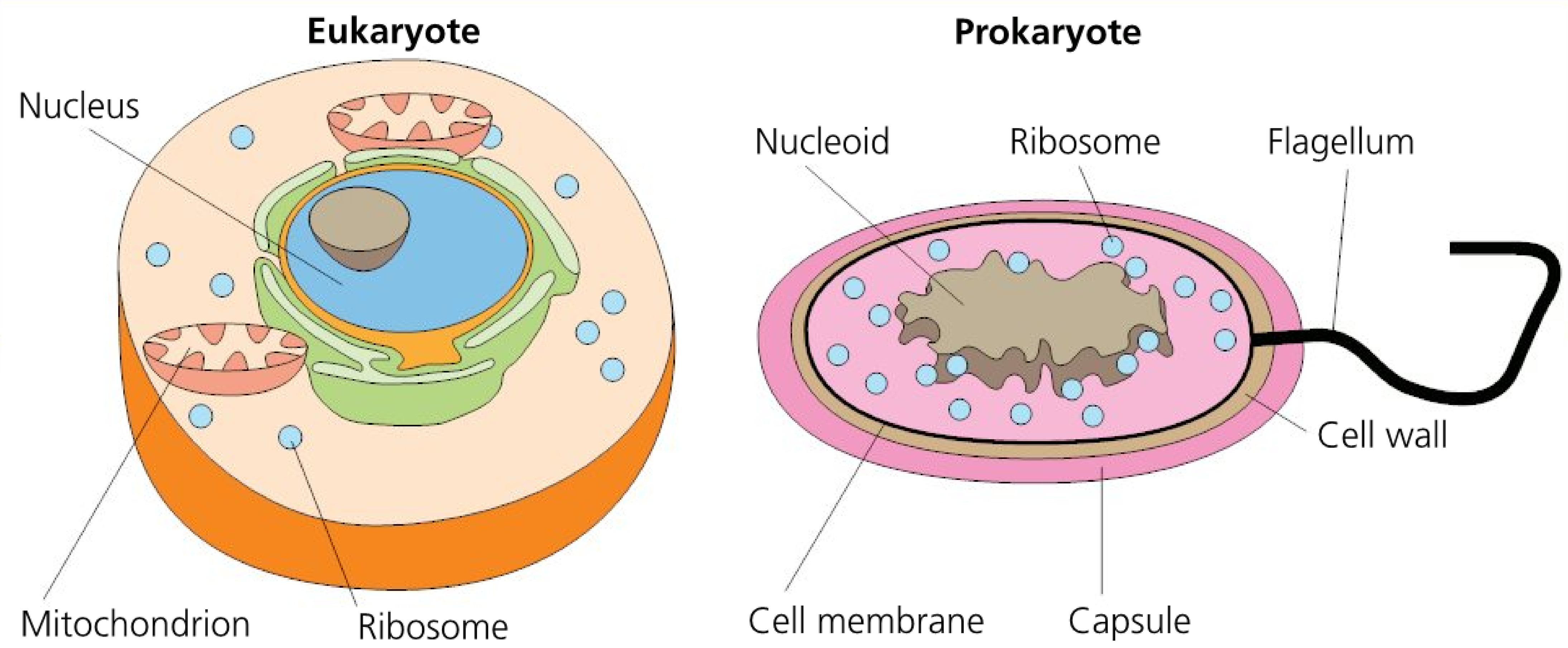
You will try to relate the concepts shown in Figure 9.3 and make connections and links between them.

Remember to log your understanding as you advance through the chapter and have a class discussion at the end to see how deeply your knowledge, critical thinking and grasp of the topics has developed. You should keep your mind focused on relating the concepts in Figure 9.3 to each other as you will need this for the last summary activity at the end of this chapter!

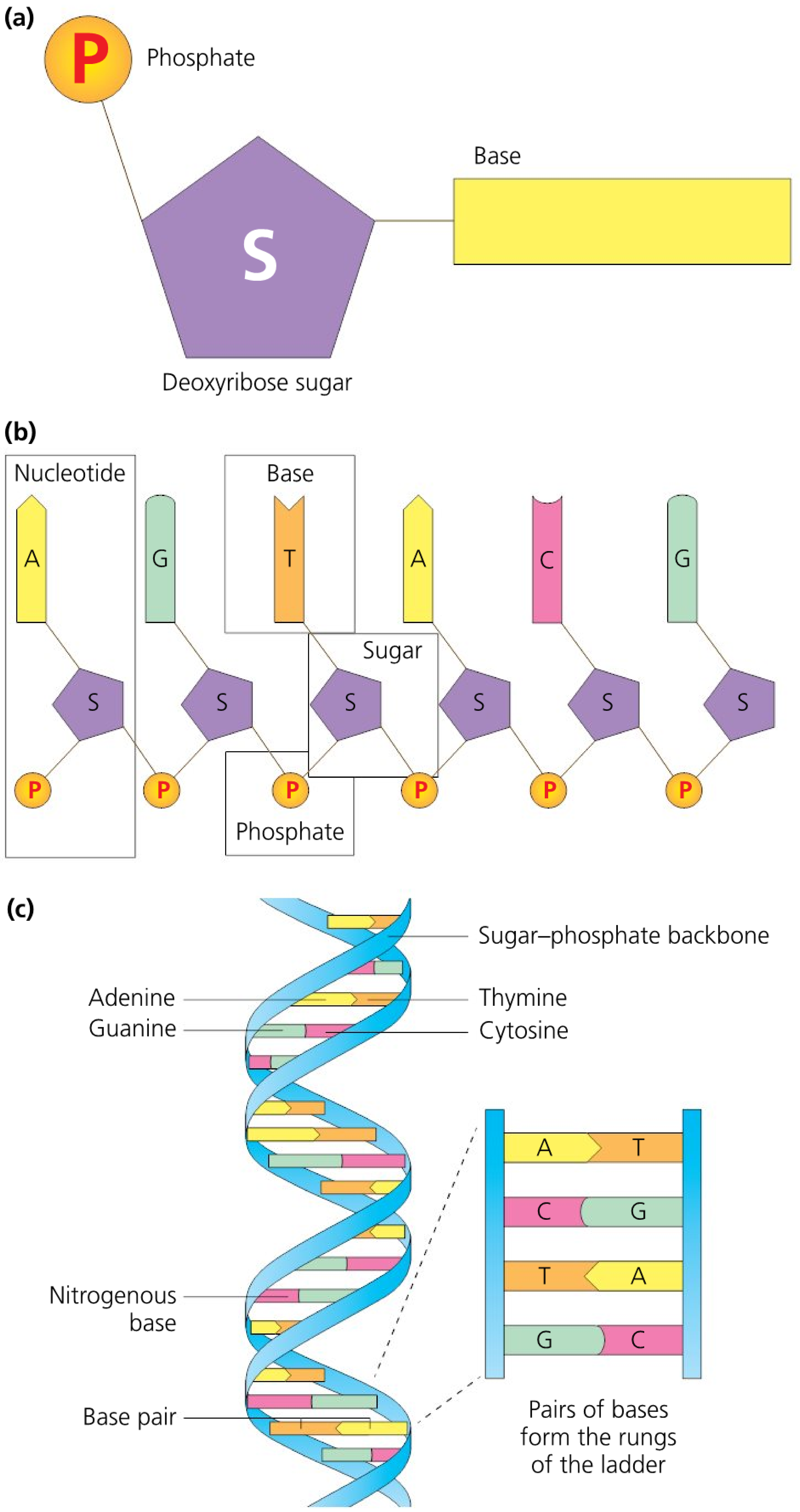
WHY CODE?

In Chapter 2 we looked at organelles and saw how each living cell packs its genetic information into chromosomes somewhere in the cell, whether confined in a nucleus surrounded with a membrane of its own (in eukaryotes) or in the cytoplasm (in prokaryotes) (see Figure 9.4). The genetic material holds all the information that cells need to function and survive, and without it there would be no life! This genetic material is held in the form of a code to send information from the 'headquarters' of the cell (the nucleus or nucleoid) to other working sites where different substances need to be synthesized and functions need to be completed. The convenience of holding the genetic material as a code will be unravelled in this section.

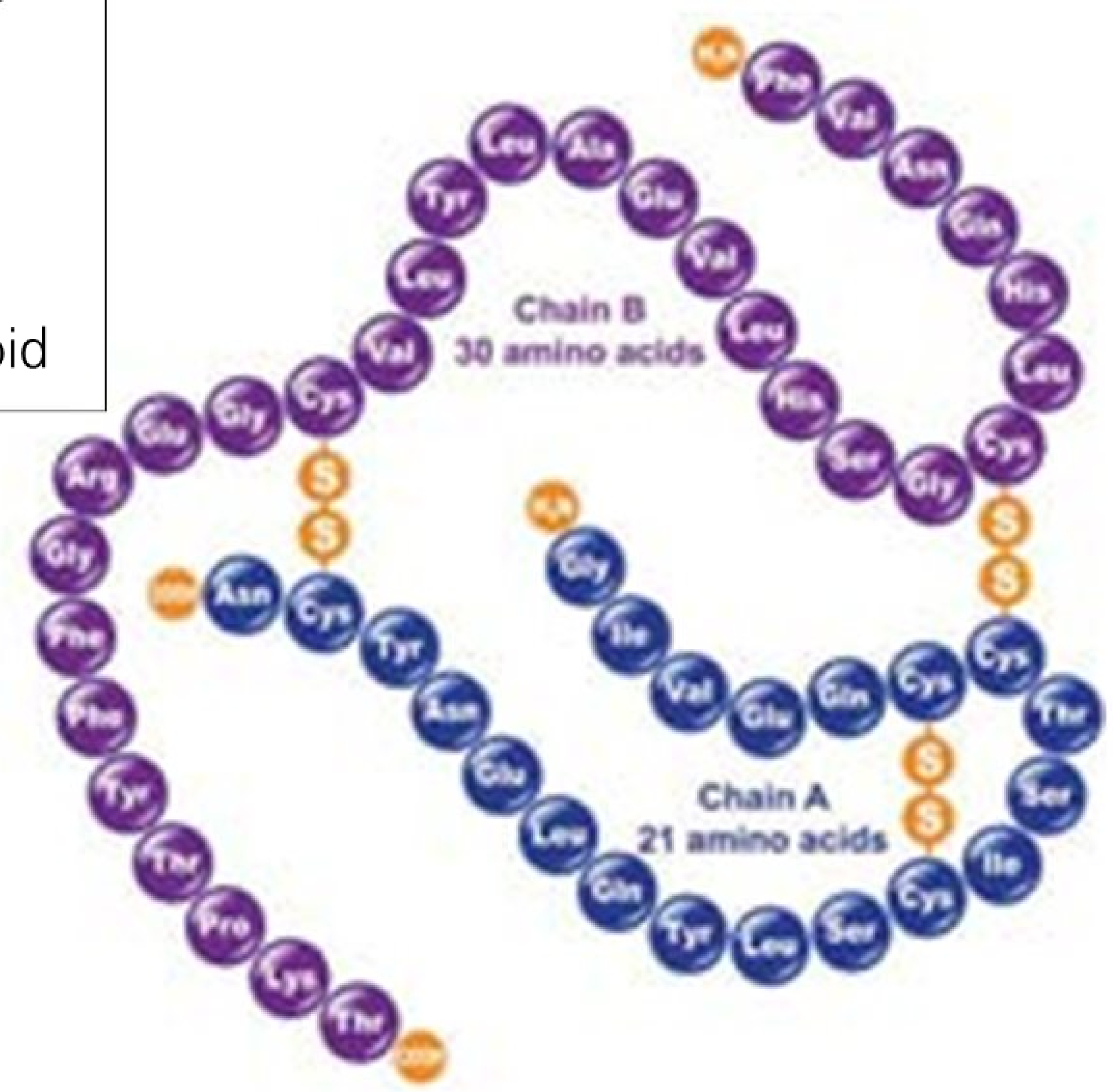
In Chapter 5 of *MYP Sciences by Concept 3* you may have explored how computers process information in the form of a code consisting of just two digits: 0 and 1. The binary code for the word '**code**' is 01000011 01001111 01000100 01000101. We saw in Chapter 8 how this information must then be converted into a form we can understand. The genetic information in cells is contained in a double helix consisting of two strands of **deoxyribonucleic acid** (**DNA**) molecules. The DNA molecules consist of building blocks called **nucleotides** (see Figure 9.5), usually referred to by the first letter of the **nitrogenous bases** (as they have the chemical properties of bases) they contain: A for adenine, T for thymine, C for cytosine and G for guanine. You may recall from *MYP Sciences by Concept 2:* Chapter 3 that the bases in the two strands join to each other in a **complementary base pairing**, where A can only bind to T and G to C. (See more on DNA in Chapter 6 of *MYP Biology by Concept 4&5*.)



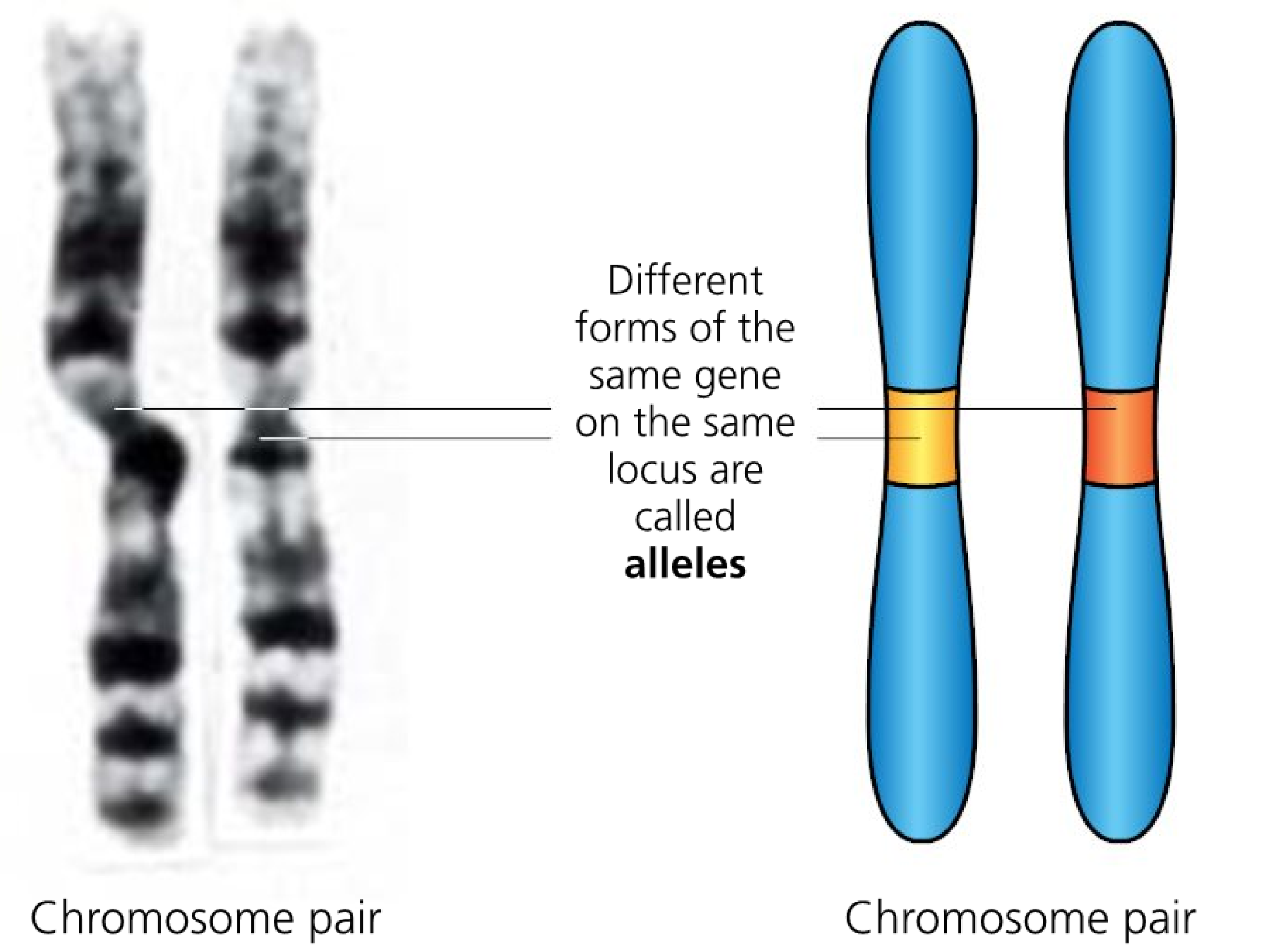
■ **Figure 9.4** Eukaryotic cell with nucleus and prokaryotic cell with nucleoid



■ **Figure 9.5** The coded structure of DNA: (a) a nucleotide; (b) a chain of nucleotides; two of these join together to make a double helix; (c) the DNA double helix



■ **Figure 9.6** Human insulin, an example of a protein made by cells to function as a hormone



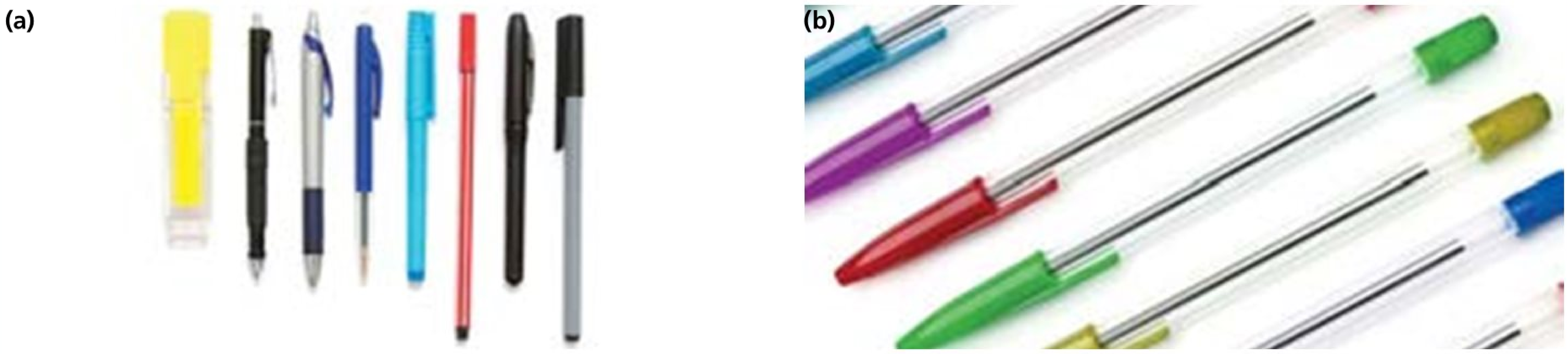
■ **Figure 9.7** Gene locus on a chromosome

DNA encodes for all cell proteins including functional proteins like enzymes or hormones, structural proteins in the plasma membrane, cytoskeletal proteins like actin, and many others (see Figure 9.6). Each protein is coded for by a segment of DNA called a gene which occupies a specific **locus** on a chromosome (see Figure 9.7). A gene can have different 'variants' called alleles, each having the same information but with little differences in the nitrogenous bases. Each gene encodes for only one specific protein but some complex proteins can have more than one gene that encode for their various parts (see more on this in Chapter 3 of *MYP Sciences by Concept 2*).

WHAT MAKES YOU SAY THAT?

If you compare these images to genes, which image would represent different genes: (a) or (b)? And which one would represent alleles of the same gene? What makes you say that?

(a) (b)

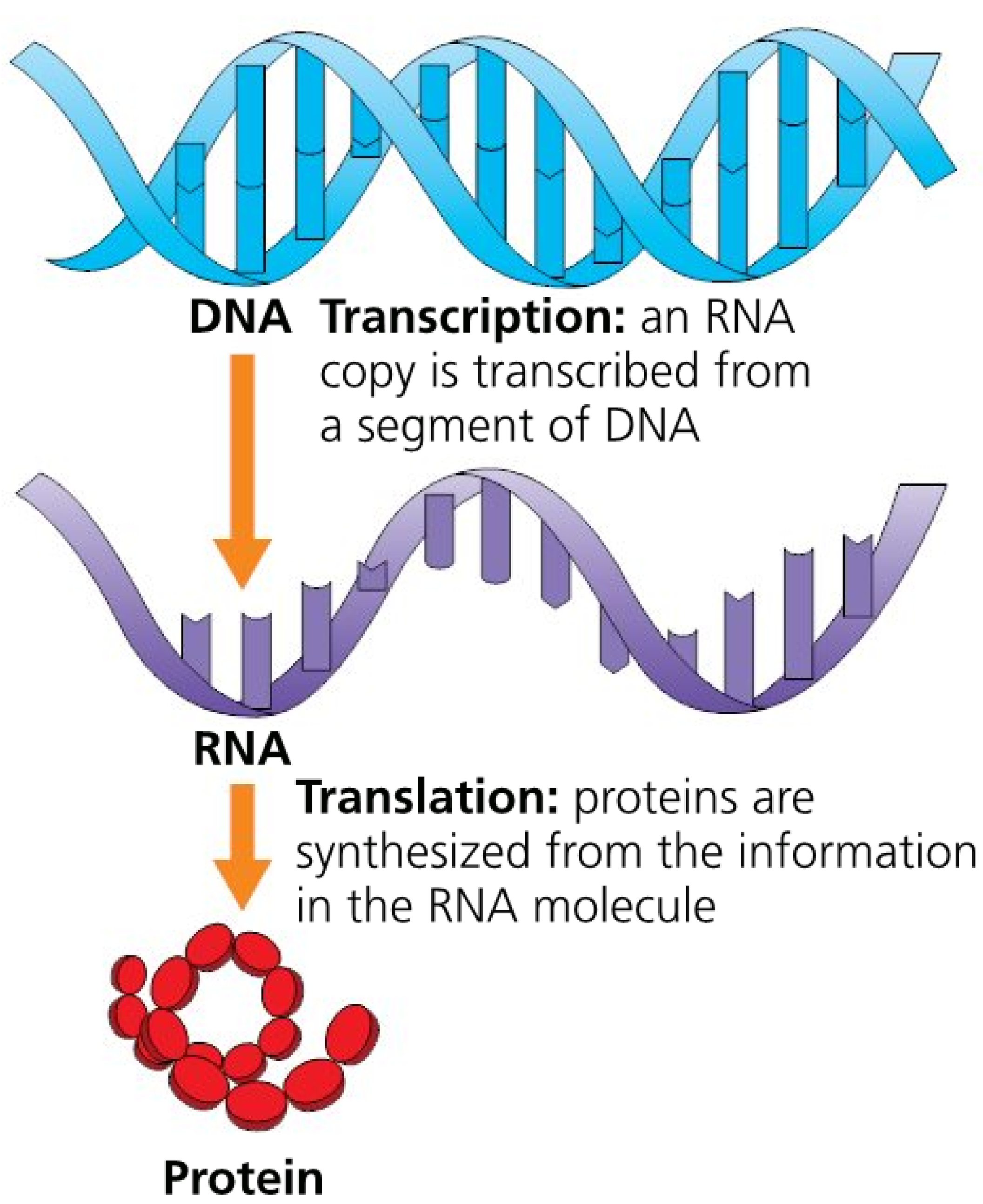


■ **Figure 9.8** Pens

EXTENSION

Build a DNA molecule: **http://learn.genetics.utah.edu/content/basics/builddna/** (requires Flash)

Then find out how more than one gene can control one function: **http://learn.genetics.utah.edu/content/basics/dnathings**



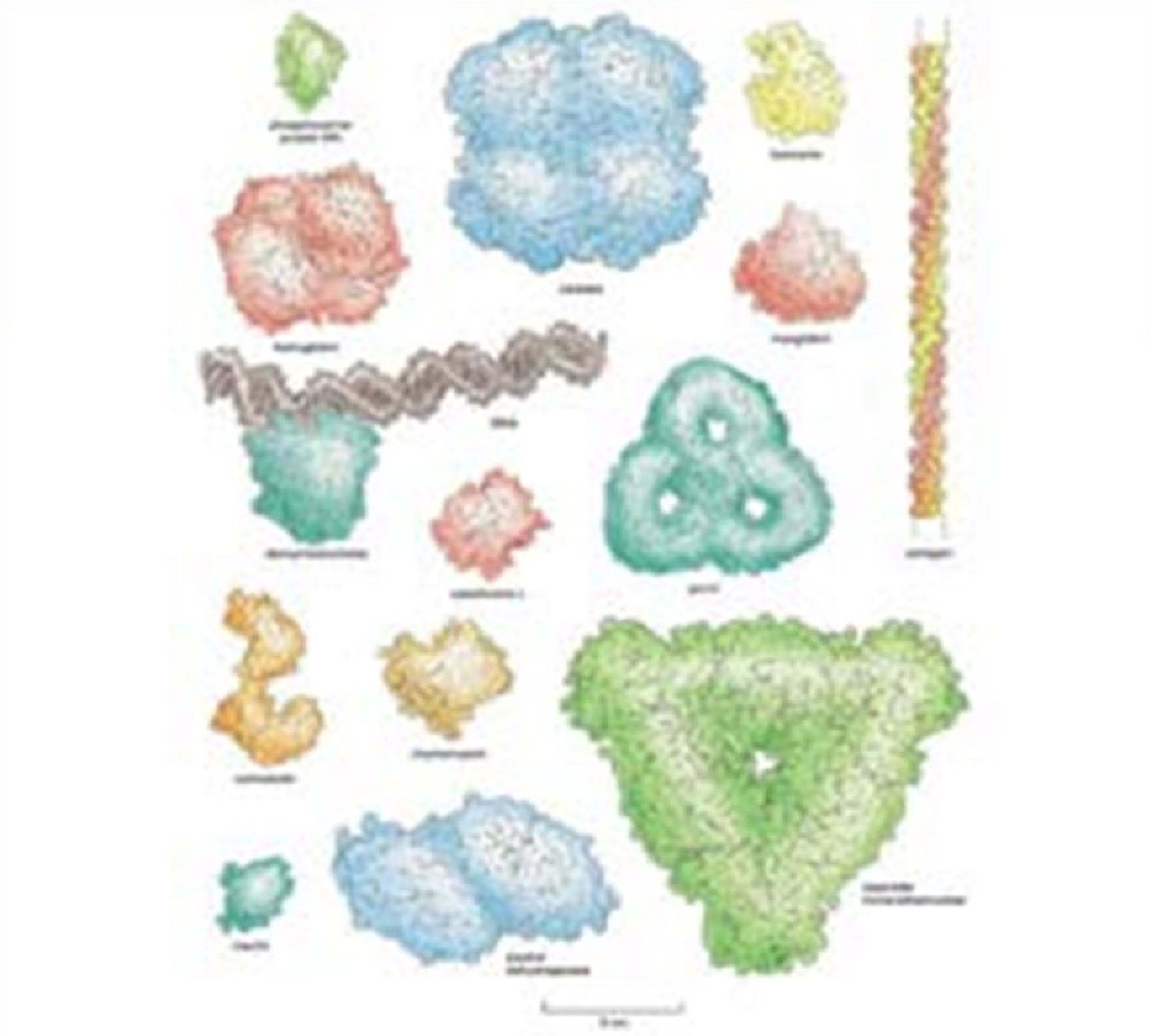
■ **Figure 9.9** Code to function

Second letter

First letter	U	C	A	F	Third letter
U	UUU UUC Phenylalanine (F) UUA UUG Leucine (L)	UCU UCC UCA UCG Serine (S)	UAU UAC Tyrosine (Y) UAA Stop codon UAG Stop codon	UGU UGC Cysteine (C) UGA Stop codon UGG Tryptophan	U C A G
C	CUU CUC CUA CUG Leucine (L)	CCU CCC CCA CCG Proline (P)	CAU CAC Histidine (H) CAA CAG Glutamine (Q)	CGU CGC CGA CGG Arginine (R)	U C A G
A	AUU AUC AUA Isoleucine (I) AUG Methionine (M): Initiation codon	ACU ACC ACA ACG Threonine (T)	AAU AAC Asparagine (N) AAA AAG Lysine (K)	AGU AGC Serine (S) AGA AGG Arginine (R)	U C A G
G	GUU GUC GUA GUG Valine (V)	GCU GCC GCA GCG Alanine (A)	GAU GAC Aspartic acid (D) GAA GAG Glutamic acid (E)	GGU GGC GGA GGG Glycine (G)	U C A G

■ **Figure 9.10** The genetic code

The information coded in the DNA is converted to functional proteins by first unravelling the 'ATCG' DNA code. This happens when the double-stranded structure of DNA is unwound and, through **transcription**, one DNA strand is converted into a single-stranded **messenger ribonucleic acid (mRNA)** (see Figure 9.9). The mRNA contains the same information as the DNA in a simpler form using an 'AUCG' RNA code instead, replacing all the thymine (T) bases with uracil (U) bases which are only found in RNA. The transcribed mRNA travels from the nucleus to the cytoplasm to meet the ribosomes which will convert the code into a physical product and produce proteins through a process called **translation**. This highly specific process converts any combination of three (nucleotides) – called **codons** – to specific amino acids; these in turn join up together to form **peptide chains** which will subsequently join up to form proteins. There are a total of 20 amino acids encoded by different codons. Different proteins have different numbers of amino acids arranged in different sequences (see Figures 9.10 and 9.11).



■ **Figure 9.11** Proteins, different in sizes and shapes

EXTENSION

1 Use the model in Figure 9.5 (page 221) and what you now know about the complementary strands in the DNA helix to **suggest** the complementary strand for this part of a DNA molecule: GGCTAATCCTTGGCCTT

2 Find out more on the processes of transcription and translation by searching: **DNA to protein videos, DNA to RNA to protein animations, how translation works, gene expression central dogma**.

3 Learn how you can find the protein and its function from a given DNA sequence: **www.yourgenome.org/activities/function-finders**

Protein name	Number of amino acids (AA) and peptide chains in the protein
insulin	**51** AA in two peptide chains: one with 21 AA and one with 30 AA
cytochrome c	**104** AA in one chain
hemoglobin	**574** AA in four chains: two with over 141 AA each and two with over 146 AA each
lysozyme (in egg white)	**129** AA in one chain
collagen	**4200** AA in three chains, each with over 1400 AA
catalase	**2000** AA in four chains, each with over 500 AA

■ **Table 9.1** Number of amino acids in some proteins

YOUR GENETIC ENCYCLOPEDIA: THE GENOME

All the genetic information in the DNA (genes and other bits of DNA that don't encode for proteins) forms a **genome**. The genome is like a genetic encyclopedia holding all the genetic information and is measured by the number of **base pairs** of DNA. (Remember DNA has two strands, so we count each pair as one base pair instead of two bases.)

SEE–THINK–WONDER

Look at Figure 9.12. What do you **see**? What does it make you **think**? What does it make you **wonder**?

All organisms of the same species have similar genomes (with some allele variations). The genome of each organism contains DNA encoding for proteins that allow the organism to perform vital functions. This universality of the genetic code allows evolutionary scientists to compare organisms of different species for similarities and so to find out how they are related. Scientists have decoded the genomes of many species in this way by **DNA sequencing**.

■ **Figure 9.12** Plant, bacteria, animal and human

QUESTION STARTS

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument; Formulate factual, topical, conceptual and debatable questions
- Information literacy skills: Access information to be informed and inform others

How could we use the genome sequences of different organisms?

Use the following 'question starts' to **formulate** your questions; write them on sticky notes and stick them on the wall.

How would it be different if …? Why …? Suppose that …? What are the reasons …? What if …? What if we knew …? What is the purpose of …? What would change if …?

Review your questions and remove the notes as they get answered through this chapter; if they don't get answered, put a star on them and do some research to find out by yourself.

Reflect and **discuss** with the class to exchange ideas and **discuss** those starred questions.

Links to: Design

Design and computing

Advances in computer technology have allowed the creation of many scientific databases. A database stores information so that it can be browsed and accessed in easy-to-use platforms and compared using analytical tools. Genetic databases facilitate the processing of complex information about genes of many organisms and were instrumental in the mapping of the human genome.

MEET A SCIENTIST: FREDERICK SANGER

Sanger (1918–2013) was a British biochemist who made numerous breakthrough discoveries. He was one of only four scientists to win two Nobel Prizes and one of only two to win them in the same category. Sanger won his two Nobel Prizes in Chemistry in 1958 and 1980, and this was surely because he was a **risk-taker** who was not afraid to carry out novel, often revolutionary, research.

Sanger studied natural sciences at St John's College in Cambridge. His first breakthrough discovery was solving the protein structure of insulin. From then he started working on RNA sequencing and DNA sequencing thereafter. He and his team sequenced the first full genome at the Laboratory of Molecular Biology (LMB) in Cambridge. They developed a new method for sequencing – the Sanger method – which is still the basis of DNA sequencing today. After his retirement, the Wellcome Trust opened The Sanger Institute, a centre for DNA sequencing near his home in Cambridge. Work at this centre was key in sequencing the human genome in collaboration with other research institutions around the world.

■ **Figure 9.13** Frederick Sanger

Sanger was a **principled** and modest scientist despite his success. When asked in 1988 about the secret of his success he replied:

> 'Of the three main activities involved in scientific research, thinking, talking and doing, I much prefer the last and am probably best at it. I am all right at the thinking, but not much good at the talking.'

ACTIVITY: How does the size of the genome relate to the number of genes in an organism?

ATL

- Information literacy skills: Process data and report results
- Critical-thinking skills: Interpret data

Before looking at the data, **suggest** which you think have more genes: bacteria, viruses, plants, animals or humans? Do you think the size of the genome correlates with the number of genes?

Table 9.2 shows some organisms. **Identify** the types of organisms shown. Do you think the selected organisms represent the diversity of life? **Suggest** other organisms you would add.

Transform the data into a suitable graph to show the number of genes in genomes of different sizes.

Hint

Because the values of these data are very large, it will be easier to use a computer graphing program or spreadsheet to draw the graph (see Chapter 2). If you use graph paper, choose your scale to fit the data.

Interpret the data in the table and graph and explain the relationship between the gene number and the genome size in the organisms. Is this relationship the same in all organisms shown in the table? Look at each organism alone and **analyse** to compare it with the rest. **Identify** the organisms that seem to stand out from this correlation.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion C: Processing and evaluating.

Organism	Genome size (base pairs)	Number of genes	Notes
Nasuia deltocephalinicola	112 091	137	this bacterium lives in a mutualistic relationship within a special organ of an insect (a leafhopper)
Epstein Barr virus (EBV)	172 282	80	virus that causes mononucleosis, also referred to as the 'kissing disease'
Helicobacter pylori	1 667 867	1589	chief cause of stomach ulcers
E. coli O157:H7	5.44×10^6	5416	strain that is pathogenic for humans; has 1346 genes not found in *E. coli* K-12 (another strain)
Saccharomyces cerevisiae	12 495 682	5770	budding yeast; a eukaryote
Drosophila melanogaster	122 653 977	~17 000	the 'fruit fly'
Homo sapiens	3.3×10^9	~21 000	human
Tetraodon nigroviridis	3.42×10^8	27 918	pufferfish
Mus musculus	2.8×10^9	~23 000	mouse
Arabidopsis thaliana	0.135×10^9	27 416	a flowering plant
Picea abies	19.6×10^9	28 354	the Norway spruce, a conifer

Table 9.2 Genes and genomes of some organisms

How do living things ensure their continuity?

Reproduction ensures the continuity of organisms by enabling parents to pass their genetic material (DNA) to their offspring, either to produce identical copies of themselves (clones) or produce diverse offspring that have a mixture of the genetic material of both parents.

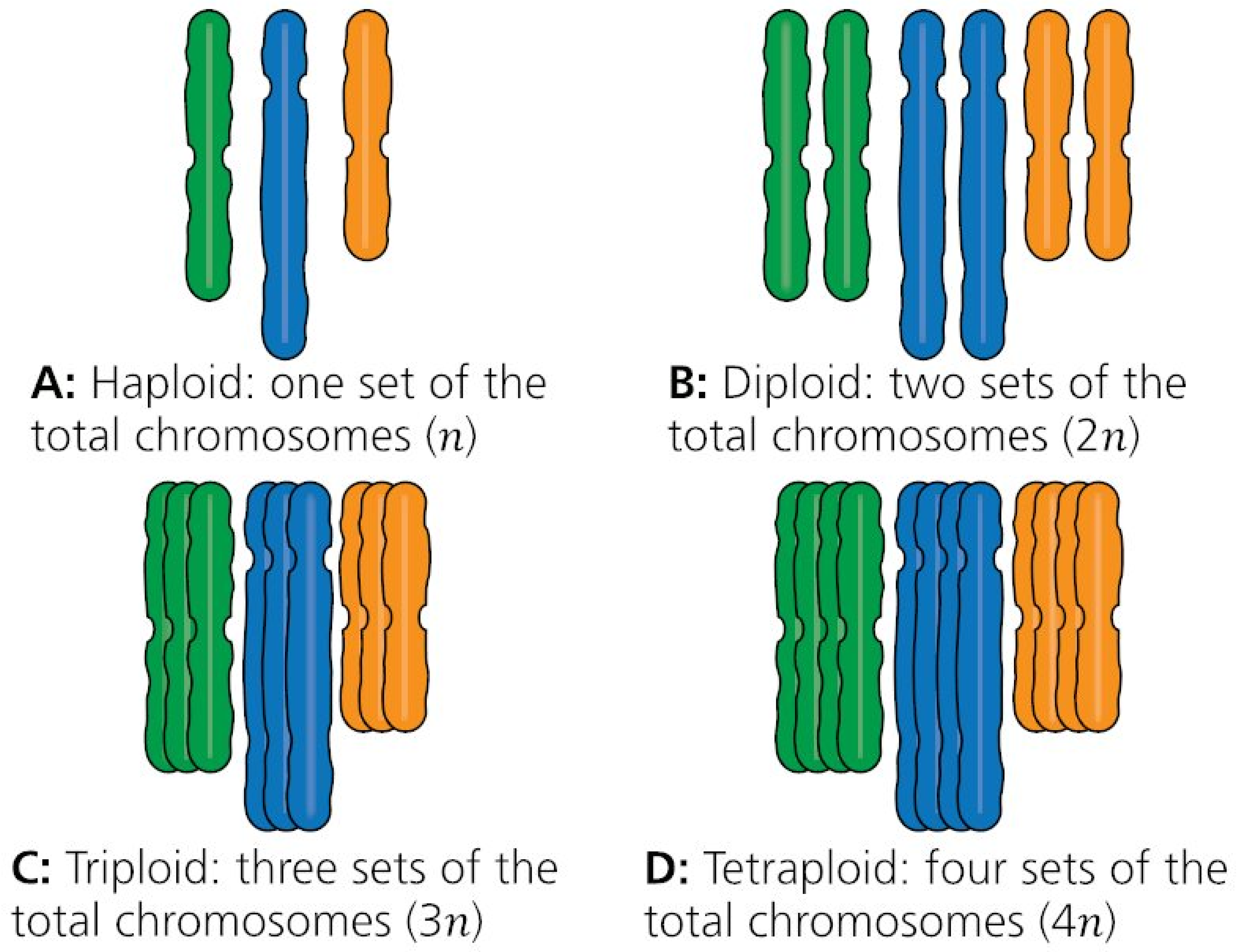
SEE–THINK–WONDER

Look at the images in Figure 9.14, showing some different species of the allium genus which includes nearly 2000 species. What do you **see**? What do you **think**? What does it make you **wonder**?

Hint

Refer to Chapter 3 to remind yourself about classification of living things.

■ **Figure 9.14** Different species of allium



■ **Figure 9.15** Ploidy: the number of sets of chromosomes in an organism. For simplicity, in this example we assume that the number of chromosomes in a set is three (humans have 23 chromosomes in a set).

The number of chromosomes in organisms can differ from one another, just like the number of genes or size of genome. Some cells have one set of different chromosomes (with one copy of each chromosome in a set), some have two sets and some have many sets. **Ploidy** is the number of sets of chromosomes in a cell of an organism and is referred to with the letter 'n'. If the cells have one set of chromosomes, they are said to be **haploid** (n); if they have two sets of chromosomes, they are **diploid** ($2n$). Some cells have more sets of chromosomes and this is known as **polyploidy**. Polyploidy gives some adaptive and evolutionary advantages to the organism. It is common in plants, especially flowering plants (angiosperms), and while most animals are diploid, it is also found in a few animals like salamanders and fruit flies.

ACTIVITY: How much is too much?

ATL

- Critical-thinking skills: Gather and organize relevant information
- Information literacy skills: Collect and analyse data to identify solutions and make informed decisions; Process data and report results

Table 9.3 represents the ploidy and number of chromosomes in some major crops.

Analyse the data and identify any patterns. What is the maximum and minimum ploidy in these examples? **Organize** the data into groups of similar **crops** then **compare** any patterns, similarities or differences within and between groups. Use the information from the ploidy and the number of chromosomes to **calculate** the number of chromosomes in each set for each crop. **Identify** which plant has the largest and smallest number of chromosomes in one set.

For example, maize has diploid cells ($2n$), each with a total number of 20 chromosomes. This means that there are two sets ($2n$) with a total of 20 chromosomes: $2n = 20$, so $n = 10$.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion C: Processing and evaluating.

Common name	Type of crop	Number of total chromosomes	Ploidy	Ploidy name
wheat	cereal	42	$6n$	hexaploid
rice	cereal	24	$2n$	diploid
potatoes	root vegetable	48	$4n$	tetraploid
soy beans	legume	40	$2n$	diploid
tomatoes	fruit	24	$2n$	diploid
bananas	fruit	33	$3n$	triploid
sugar cane	grass	80	$6n$	octoploid
sugar beet	root vegetable	18	$2n$	diploid

Table 9.3 Ploidy of some major crops

EXTENSION

Search the terms: **ploidy, chromosome number in organisms**. Look for the organisms that have the most and least number of chromosomes, then find out their ploidy. **Identify** any correlation between the complexity of the organisms and their ploidy.

Suggest how organisms will replicate and pass on their DNA to their offspring if it is organized in chromosomes inside a nucleus. Search the term: **DNA replication**. **Suggest** how the number of chromosomes affects the rate of the replication process.

How do organisms reproduce?

Reproduction is a fundamental characteristic of life. All organisms are innately programmed to reproduce in many different ways: unicellular or multicellular; prokaryote or eukaryote; using a reproductive system or not; internal or external fertilization; offspring that can grow inside the mother's body or outside.

DO ALL ORGANISMS NEED SEX CELLS TO REPRODUCE?

It is possible for organisms to reproduce without the need for a partner or reproductive systems or sex cells. Some organisms, mostly prokaryotes (and a few eukaryotes), reproduce from their body cells through asexual reproduction. In this case, a single parent will give rise to **clones**; offspring that are genetically identical to it (with exactly the same DNA as the parent). This can happen in many ways.

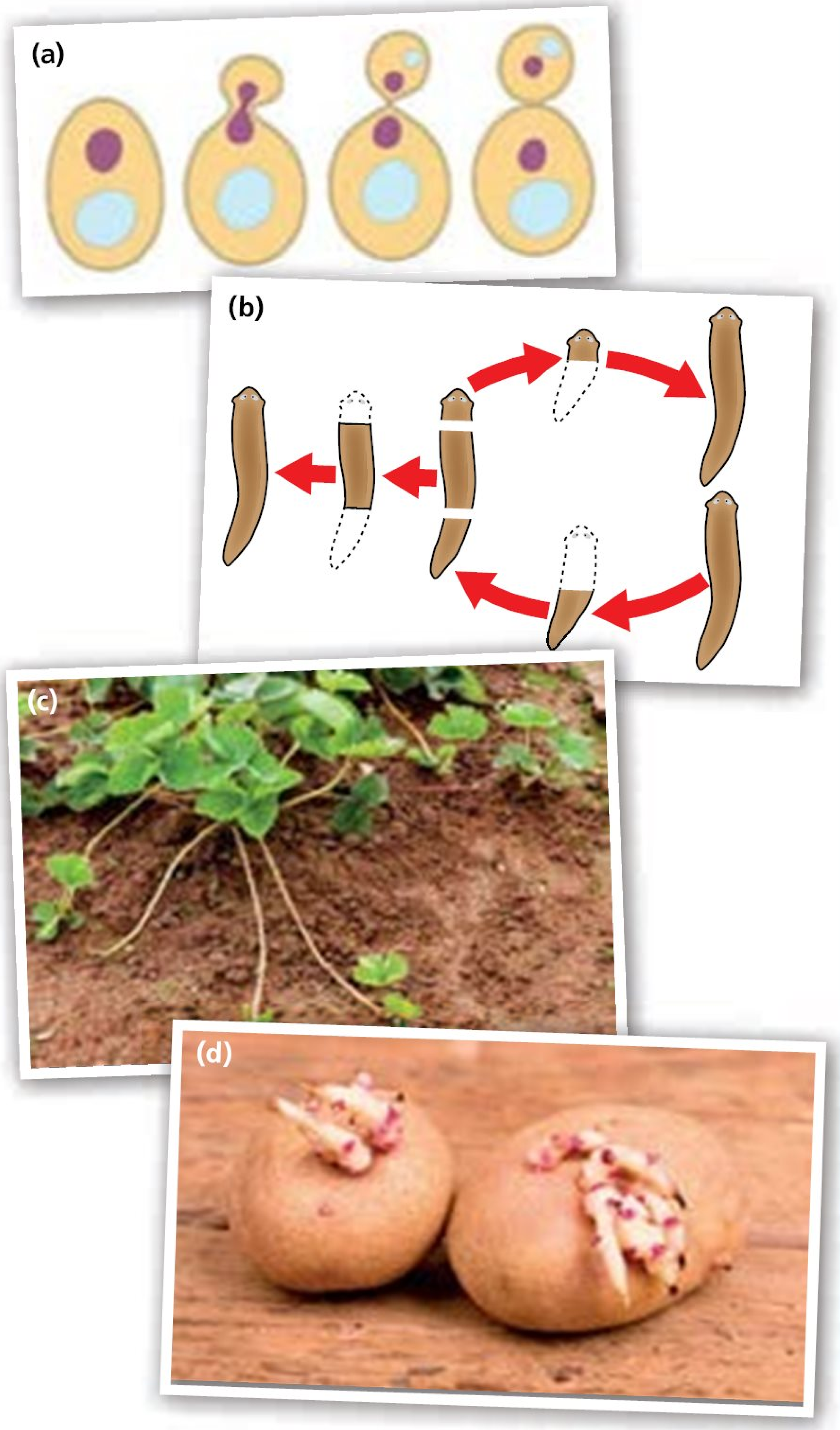
Unicellular prokaryotes (mostly bacteria) can reproduce very quickly by binary fission resulting in two genetically identical daughter cells. The DNA in these organisms consists of one long chromosome, so when they reproduce they first duplicate (make a copy) of this chromosome and each new daughter cell takes one copy. Watch *Paramecium* divide by searching videos for **paramecium division**.

Budding is when a unicellular or multicellular organism reproduces to give rise to genetically identical offspring which bud off the body of the original organism (Figure 9.16a). This happens in both yeast and hydra:

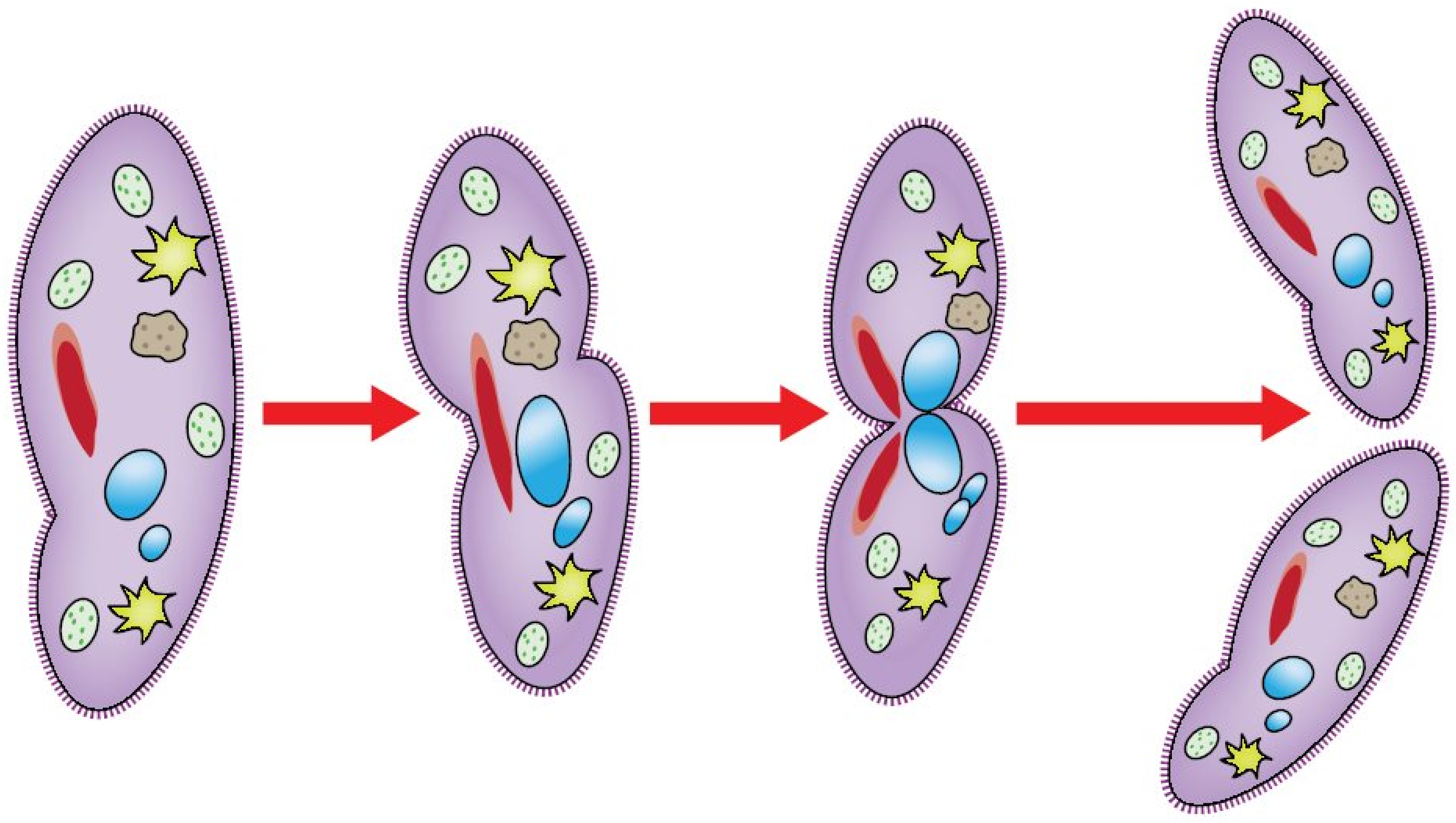
- yeast (unicellular organism): **www.youtube.com/watch?v=iOvrq6ssy2Y**
- hydra (multicellular organism): **www.youtube.com/watch?v=wRk5MFhZofA**

THINK–PAIR–SHARE

Look at the images below and **think** about what type of reproduction is shown in each case. **Discuss** your thoughts in **pairs** then **share** and **compare** your conclusions with the class, **explaining** your reasoning.



■ **Figure 9.16** Spot the reproduction differences



■ **Figure 9.17** Binary fission in *Paramecium*

ACTIVITY: How can organisms reproduce?

ATL

- Communication skills: Organize and depict information logically
- Critical-thinking skills: Gather and organize relevant information to formulate an argument

Copy and complete Table 9.4 by **stating** which reproductive method can be used by which type of organism.

- **Suggest the reason why some organisms can reproduce with one method but not the other.**
- **Evaluate whether the asexual reproduction methods mentioned before are suitable for all organisms.** For example can an animal reproduce by propagation? Can a plant reproduce by binary fission?
- **Outline other possible reproduction methods for organisms that cannot use the methods stated above.**
- **Demonstrate possible advantages for using these other methods.**
- **Explain what would happen to the clones generated by the asexual reproduction methods above if the parent organism was infected by a virus.**
- **Evaluate the advantages and disadvantages if all living organisms reproduced in a way that produced clones.**

Assessment opportunities

- This activity can be assessed using Criterion A: Knowing and understanding.

Asexual reproduction method	Unicellular or multicellular?	Eukaryote or prokaryote?	Additional notes/exceptions
binary fission			
budding			
fragmentation			
propagation			
mitosis			

Table 9.4 Who can use which asexual reproduction method?

Fragmentation is when a new organism can grow from a fragment that breaks off the body of the original organism, as is the case for some worms and starfish (Figure 9.16b). The new organism should be a clone of the original but because the fragments split up from parents and develop away from them, it is possible that some environmental factors affect the new offspring and make them different from the original parent. Search the terms: **fragmentation regeneration, starfish regeneration, worm regeneration** for more information.

Some plants, like strawberries (Figure 9.16c), reproduce by propagation to produce plantlets identical to the original plant. Some other plants reproduce by tubers (potatoes, Figure 9.16d) or bulbs (onions). The new plants will be clones of the original.

Mitosis is mainly used for growth but a group of eukaryotic organisms called **protozoa** also use it for reproduction. These are unicellular organisms with animal-like behaviour, such as amoeba. Protozoa have a nucleus with more than one chromosome which first needs to duplicate before dividing so that each one of the new cloned daughter cells gets exactly the same genetic content as the mother cell. Mitosis in eukaryotes works similarly to binary fission in prokaryotes to duplicate more than one chromosome. The ploidy of the new daughter cells remains the same, so if a cell was diploid ($2n$), it will divide and give rise to two new diploid cells ($2n$ each), because the chromosomes duplicate before dividing. Mitosis involves an orderly series of complex events which will be covered later.

EXTENSION

Search the terms: **parthenogenesis, hermaphroditism, apomixis**. What is special about these types of asexual reproduction?

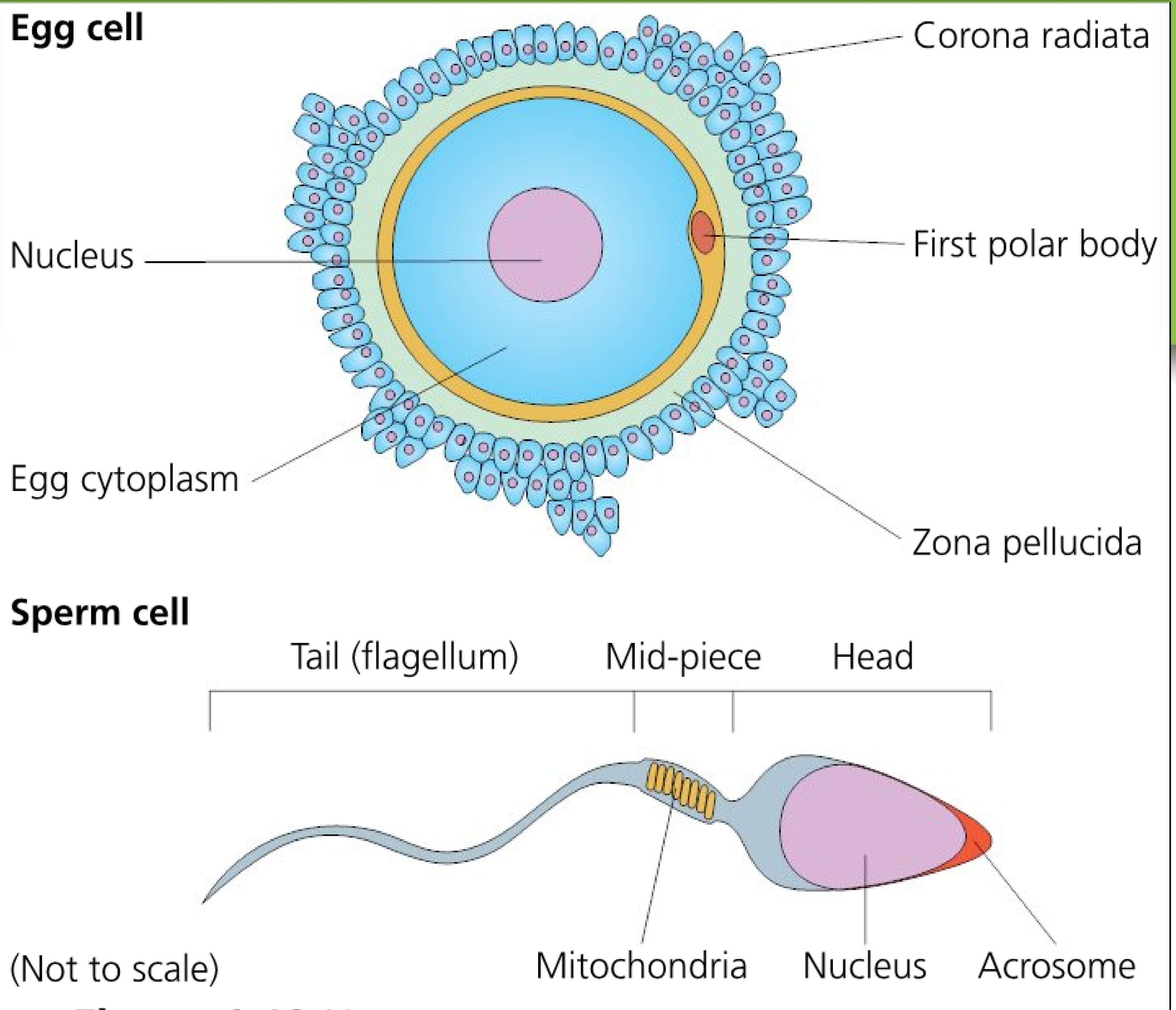


Figure 9.18 Human gametes

WHY ARE SEX CELLS NEEDED IN REPRODUCTION?

Having reviewed the different methods of asexual reproduction, we have seen that some organisms would not be able to use any of those methods because they are too complex. Humans, for example, cannot use asexual methods to reproduce and pass all the DNA held in the 23 pairs of chromosomes required to build a complex body. As organisms increase in their level of complexity, asexual reproduction becomes unsuitable and these organisms use sexual reproduction. This requires two parents of different gender to produce specialized cells called gametes (Figure 9.18) in order to mate. Males produce **sperm cells** and females produce an **ovum** or egg. In some complex plants these cells are the **pollen** and ovum, respectively.

Gametes have shapes, features and characteristics which allow them to complete their reproductive functions.

Gametes which hold the DNA of each parent fuse together during fertilization to form a zygote which will develop into an **embryo** and eventually into a new organism. The offspring in this case are not clones but have half their DNA content from each parent. This offers organisms that reproduce sexually the advantage of **diversity**, which confers an evolutionary advantage as it allows for new adaptations to the environment and better chances of survival. For example, if a parent is **susceptible** to a disease, this is not always passed on to the offspring.

Other ways to carry out scientific inquiry

Scientific inquiry doesn't always need to be experimentally based. Scientists conduct their investigations in many other ways including computer simulations, comparison and analysis of data from electronic databases, as well as carrying out a literature review of published **secondary data**. However, these other types of investigation still require that scientists follow a scientific method.

For example, you may compare the effect of different types of drugs on a disease. It will be hard to conduct an experiment yourself, but you can collect secondary data from published sources. You may choose to compare categoric independent variables (different drugs) or different values of the same variable (continuous data) such as different concentrations of an active ingredient. As for the dependent variable, you may measure the success rate of the treatment by comparing pain relief or the time it takes for healing. You would need to *control* variables to make sure that all patients are comparable. The treatment should also be comparable: the patients should take the drug for the same length of time. The materials you use will be the databases, articles and sources from which you obtained the secondary data (preferably also limiting the publication date to the same period of time, for example the last 5 years). The method needs to clarify how and where you found the articles, what type of data will be extracted and all the steps you followed for this. Once you finish the inquiry and design stage, you can follow the usual data processing and evaluation section of the MYP *Sciences Inquiry Cycle*.

ACTIVITY: Similar but not quite the same …

ATL

- Information literacy skills: Collect, record and verify data; Process data and report results; Evaluate and select information sources and digital tools based on their appropriateness to specific tasks

In this activity you will **compare** the physical or functional characteristics that make male and female gametes in plants and humans different from one another. Your comparison should focus on how their structure helps them to complete their function: to mate.

Follow the guiding questions below and collect data by conducting scientific inquiry using secondary data.

- **Compare their life span, number or size and so formulate a research question.**
- **Identify variables to be controlled. When conducting research on secondary data, you must control parameters in your searches to have reliable data.**
- **Use scientific knowledge to suggest a hypothesis about the relationship between your variables; justify your reasoning with scientific evidence.**
- **List the sources of your data and the search restrictions you will apply.**
- **Outline the method of your research, showing step by step how you look for articles and data.**
- **Are there any safety issues that need addressing in such investigations?**
- **Once you collect the data, organize and transform it so that it can be interpreted.**
- **Describe your findings in a conclusion; explain or justify any relationships.**
- **Evaluate your hypothesis, method and any sources of errors in your investigation.**
- **Don't forget to document your sources.**

Assessment opportunities

- This activity can be assessed using Criterion B: Inquiring and designing and Criterion C: Processing and evaluating.

ACTIVITY: Made to mate!

ATL

- Critical-thinking skills: Gather and organize relevant information
- Information literacy skills: Understand the benefits and limitations of personal sensory learning preferences when accessing, processing and recalling information

Look at the images of human gametes in Figure 9.18. Extract the information needed to complete a copy of Table 9.5 and deduce how each part or feature of the gamete helps it perform its function.

When you have finished, **compare** the features of the egg and sperm cell. Consider their chromosome content: do they have the same type of chromosomes?

Assessment opportunities

- This activity can be assessed using Criterion A: Knowing and understanding.

Part of the gamete	Male or female gamete (egg/ovum or sperm/pollen)	Function it allows
nucleus	both	contains the genetic information from parents in the form of DNA organized in chromosomes
tail (flagellum)		
		barrier for entry of gametes
		pointy shaped to allow easy penetration
		contains digestive enzymes
middle piece		
		layer of cells that provide nourishment and support for the gamete

Table 9.5 What part of the gamete helps it complete its function?

EXTENSION

Compare human gametes to plant gametes. **Identify** the main differences. Why are there features in plants that are absent in humans and vice versa? **Discuss** how the structure of humans and plants dictate such differences. Search the terms: **ovum, ovule, plant egg and polar nuclei**. Which female gamete do you think is more complex, the human or plant one?

DISCUSS

How will the male and female gametes meet to fertilize? Which gamete stays in one place and which one travels? Think of the reproductive systems in humans and plants and discuss how they are going to create 'meeting opportunities' for the two gametes.

ACTIVITY: Peeling the fruit: understand the concept before the content …

ATL

- Organization skills: Use appropriate strategies for organizing complex information
- Critical-thinking skills: Analyse complex concepts and projects into their constituent parts and synthesize them to create new understanding
- Reflection skills: Develop new skills, techniques and strategies for effective learning; Consider content

Consider what you have learnt so far about asexual and sexual reproduction. Update your 'peel the fruit map' with the new concepts and connections and add any new questions you have now.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

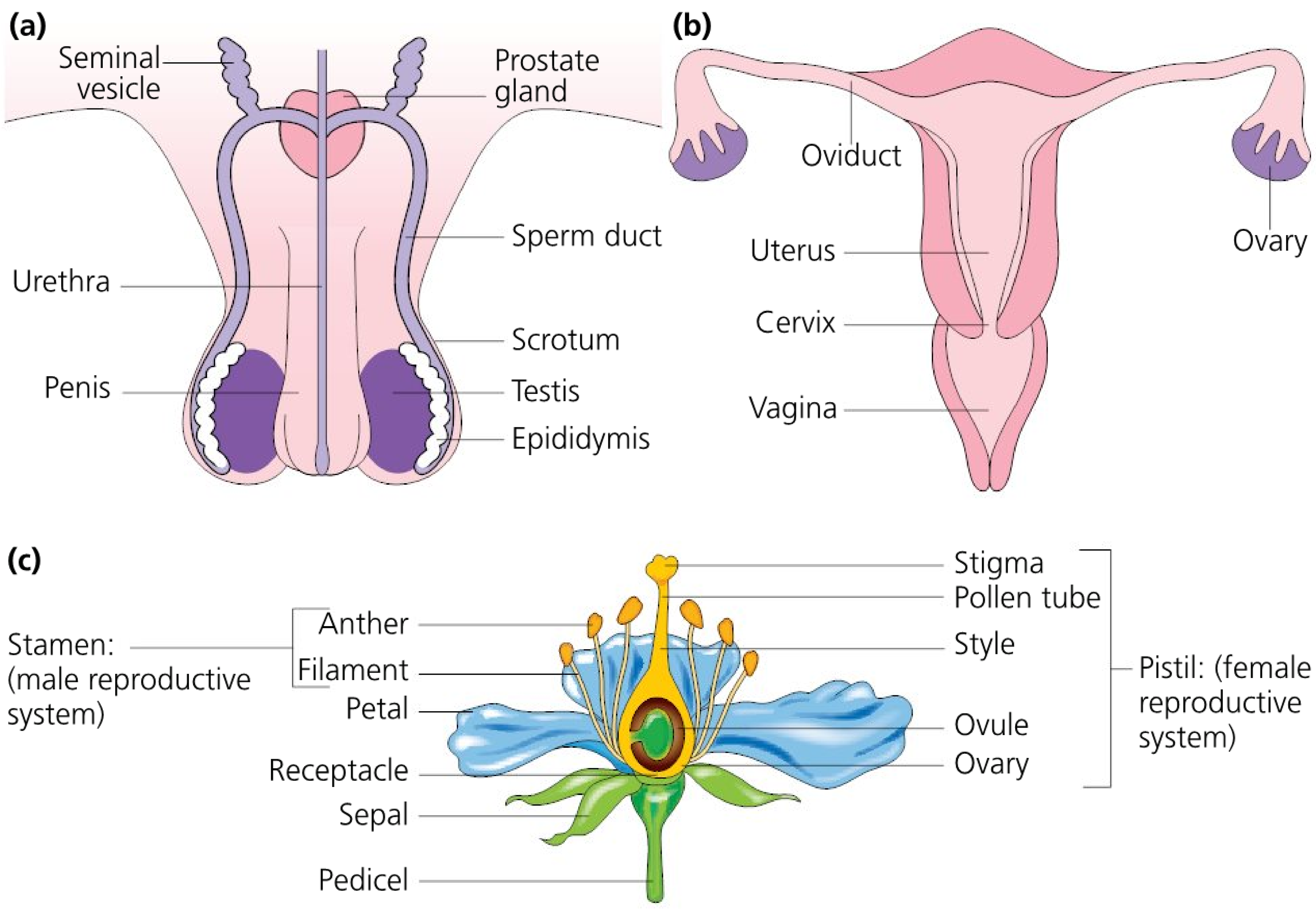


Figure 9.19 (a) Human male, (b) human female and (c) plant reproductive systems

EXTENSION

Some organisms reproduce with both asexual and sexual reproduction. **Find** out examples of these organisms and **summarize** their methods of reproduction using mind maps or other visual organizers.

SEE–THINK–WONDER

Look at Figure 9.19. What do you **see**? (What features, organs, structures, levels of complexity?)

What does it make you **think**? (Compare these systems to heating systems: some have 'outside fitted heaters' like radiators, others 'hidden heating systems' like underfloor heating!)

What does it make you **wonder**? (How is this difference in the reproductive systems linked to their function? What else does it make you **wonder**?)

Gametes are produced and then develop in **reproductive systems** which consist of organs that allow sexual reproduction. The organs of the human male reproductive system ensure the production of sperm cells in the **testes** held in a sack called the **scrotum**. After maturation in the **epididymis**, the sperm cells are able to move and they travel through the **sperm ducts** to join the **urethra** in the penis. This provides an exit channel for them to leave the male body in a process called **ejaculation**. For the sperm cells to move through the reproductive system, they are mixed with liquid contents produced by other organs within the system: the **seminal vesicles** and the **prostate glands**. These facilitate the transport of sperm cells and the contents together form a sticky white liquid called **semen**.

EXTENSION

Research different methods of pollen dispersion from one plant to another, keeping in mind that some plants have both the male and female reproductive systems, which makes it much easier for the pollen to reach the egg!

In plants, **stamens** form the male reproductive system and each stamen consists of two organs: the **anther** which produces pollen and the **filament** which holds the anther. The pollen leaves the stamen and gets dispersed in various ways to reach the female reproductive system and fertilize the egg.

The human female reproductive system consists of two ovaries on either side of the **uterus**. Each ovary contains a fixed number of eggs that are then released after a woman reaches sexual maturity (at puberty). Usually one ovary produces one ovum at a time each month, although sometimes multiple eggs can be released. The ovary is joined to the uterus by an oviduct, a tube that carries eggs from the ovary to the uterus during ovulation. The uterus is a muscular organ that provides space for a developing baby during pregnancy and is isolated from the outside world by the **cervix** to prevent infections. The cervix joins to the vagina, the last organ of the female reproductive system. The latter provides the birth canal for the baby and the entry site for sperm cells when they travel to reach the oviduct and fertilize the egg.

In plants the female reproductive system is called a **pistil** that contains one or more **carpels**. Each carpel consists of a **stigma** and a **style**. The stigma acts like the landing platform for the pollen during fertilization. Once landed, the pollen slides down the style which transports the pollen to the ovules in the ovary. Each ovule contains the eggs which will be fertilized by the pollen and develop into seeds.

EXTENSION

We looked at **internal fertilization**, where the male gamete fertilizes the female gamete inside the reproductive system. Research **external fertilization** and find examples of organisms that use this type of sexual reproduction. Search the terms: external and internal fertilization.

ACTIVITY: Map out the fertilization process

ATL

- Critical-thinking skills: Gather and organize relevant information
- Information literacy skills: Collect and analyse data to identify solutions and make informed decisions; Process data and report results

In this activity you will **apply** the knowledge you have gained about reproductive systems and map out the path of the male gametes through the female reproductive system to complete fertilization in humans.

Draw a sequence diagram with arrows from one box to another and **annotate** the different stages of fertilization, stating in which organ they occur. You may follow the example in Figure 9.20 which outlines some steps that happen in the male reproductive system and complete what happens when sperm enter the female reproductive system.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

sperm cells →	sperm cells mixed with other content to form semen →	semen ejaculated →	
produced in testes	**produced in seminal vesicles and prostate glands**	**from urethra**	....

Figure 9.20 Sequence diagram of fertilization in humans

EXTENSION

What happens if more than one egg gets fertilized? What is the difference between identical and fraternal twins? Are identical twins considered clones? What do you know about multiple births?

Find some videos by searching: **formation and fertilization of identical twins, fertilization of a single egg, single and multiple egg fertilization**.

Links to: Physical and health education

Personal and social education or guidance

You may have a programme of guidance or personal and social education in your school, or you may look at aspects of body change and development in your MYP PHE programme. The hormonal changes that occur around puberty as we reach sexual maturity can bring with them some complex psychological changes too, as we learn to adapt to our growth and make the transition from child to adult. You may discuss this and any questions you have with your science teacher to find out the scientific explanations for all these changes.

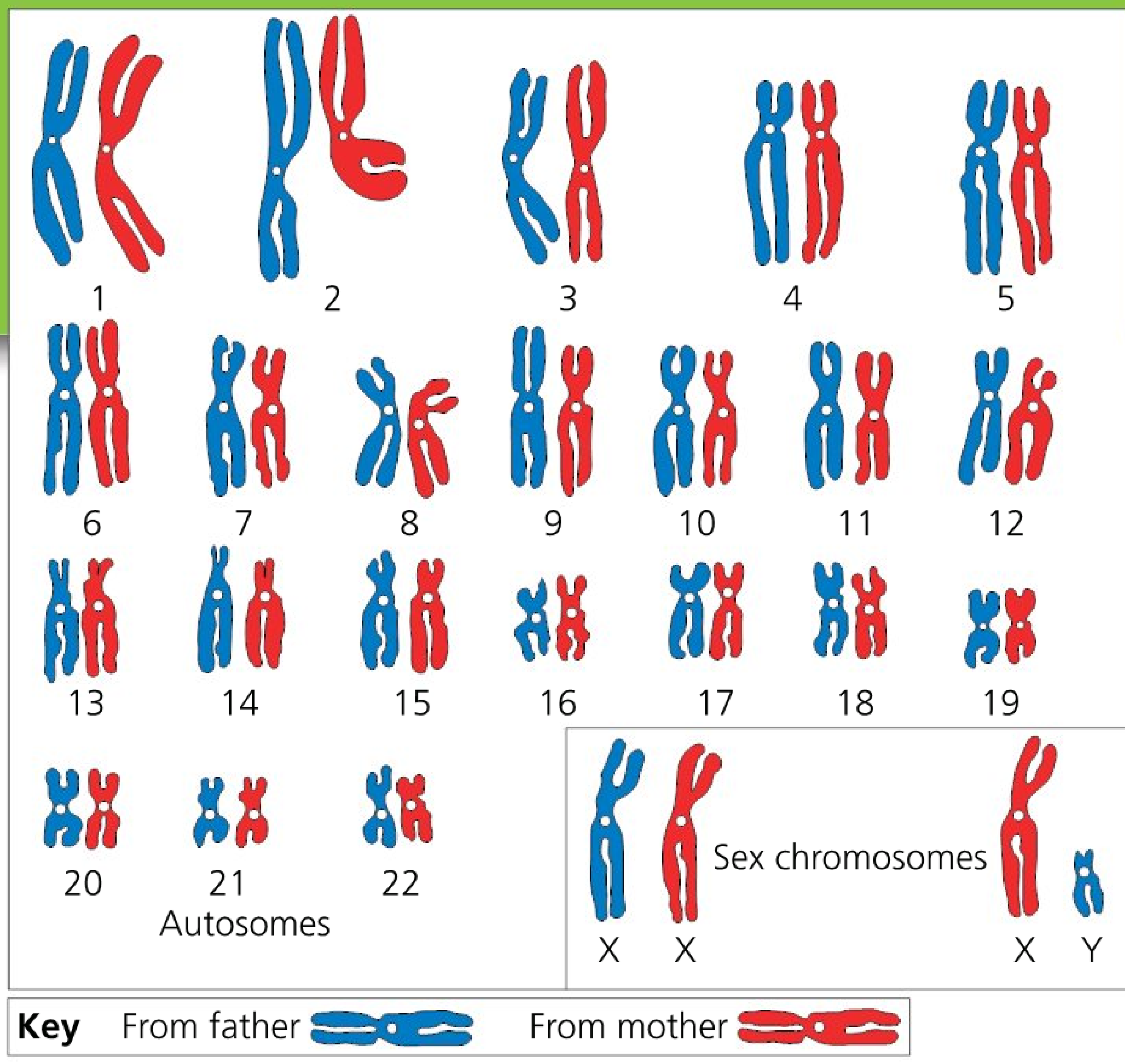
CIRCLE OF VIEWPOINTS

ATL

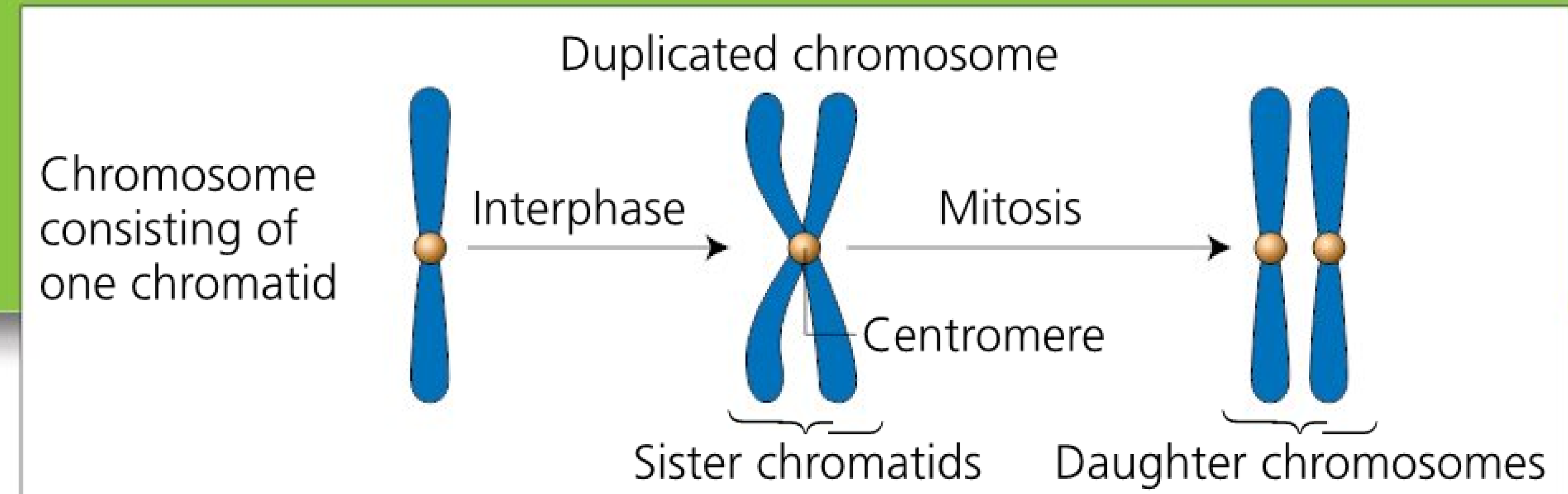
- Critical-thinking skills: Consider ideas from multiple perspectives

Living organisms are innately programmed to reproduce naturally, but humans have intervened in this process through different techniques such as contraception, *in vitro* fertilization (IVF), use of insemination donors, etc.

- **Brainstorm a list of perspectives on the methods used by humans to intervene in reproduction and summarize these in outline. Use this outline to explore each method and to prepare a presentation to the class expressing your viewpoint:**
  - **I am thinking of ... [the topic] ... from the point of view of ...**
  - **I think ... [describe your viewpoint; be an actor – take on the character of your viewpoint]**
  - **A question I have from this viewpoint is ...**
- **Take turns to speak about your viewpoints and record them on the board.**
- **What new ideas and questions do you have now?**



■ **Figure 9.21** Humans have two sets of 23 chromosomes: one set from the mother and another from the father



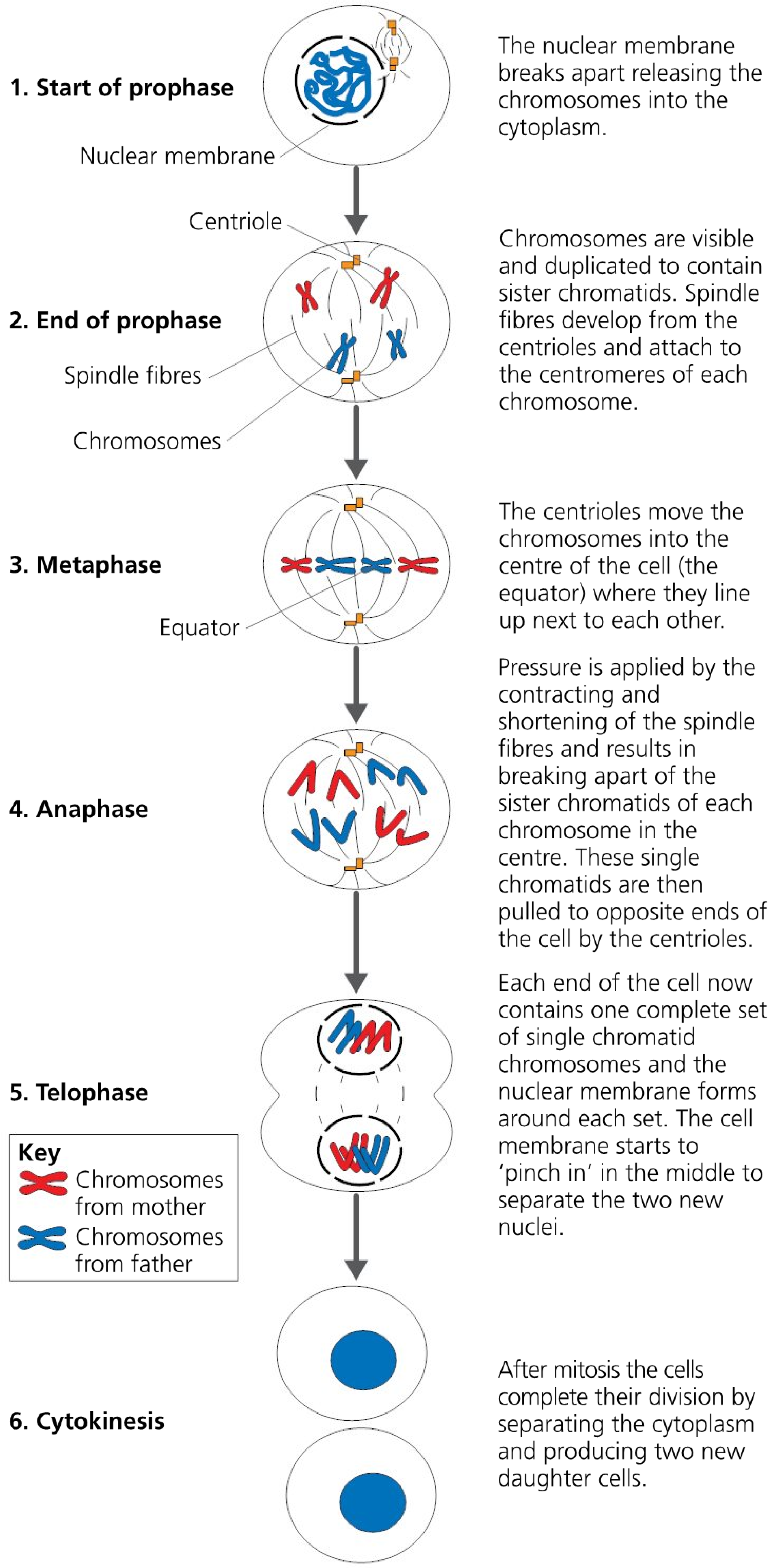
■ **Figure 9.22** Chromosome duplication showing sister chromatids

DIVIDE TO GROW OR DIVIDE TO MATE

We have seen that sex cells need to fuse during fertilization in order to form an embryo. We will next look at how these gametes ensure that they only pass the genetic information to the offspring in a desirable number of chromosomes.

Consider the example of the diploid human cells ($2n = 46$) where each cell has 23 pairs of **homologous chromosomes**. Each pair has one from the mother and another from the father. Of these, 22 pairs are **autosomes** while the 23rd pair represent **sex chromosomes**. These determine the gender of the person (XX in human females and XY in males). This pair contains one chromosome from the mother (always X) and another from the father (X or Y).

Mitotic division produces two identical clones from an original parent cell, each with the same ploidy as the parental cell. So mitotic division of a diploid human cell will result in two new diploid cells. For this to happen, the chromosomes which usually have a single **chromatid** must duplicate at the end of the **prophase** stage to produce a **sister chromatid** for each chromosome. This shows the chromosomes in the form of an 'X' with two identical sister chromatids. Mitosis then continues over three more stages: **metaphase**, **anaphase** and **telophase**. Mitosis is followed by **cytokinesis** which is when division is completed by dividing the cytoplasm to form two new cells. The cells then enter **interphase** where they carry out the functions of life and get ready for further cell divisions.



■ **Figure 9.23** Stages of mitosis

ACTIVITY: Colourful mitosis

ATL

- Critical-thinking skills: Use models and simulations to explore complex systems and issues

In this activity you will test your understanding of mitosis by modelling the stages shown in Figure 9.24 with coloured modelling clay. If you don't have clay, you can use pipe cleaners or coloured string.

Method

- **Construct a model on a piece of A4 paper by first drawing the cell membrane, spindles, nuclear membranes, etc. To simplify the process, model a diploid cell with only two sets of chromosomes. How many chromosomes does the cell have in total? How many chromosomes will you put in each pair? Should the chromosomes be the same colour or should they be two different colours? You can cut the clay to make chromosomes of different sizes: tall and short. Will each pair have one tall and one short chromosome or will you have one short pair and one long pair (think of homologous pairs)? How many chromatids will your chromosomes have at the first stage of mitosis?**
- **Place your chromosomes on the paper on which you drew the other features of the cells.**
- **Complete the stages of mitosis using a new labelled piece of paper for each stage.**
- **Display your model on the table and go around the classroom to see the displays of other students.**
- **Correct your model if you noticed any mistakes on looking at those of your peers.**
- **Present your model to the class, explaining what happens in each stage of mitosis.**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

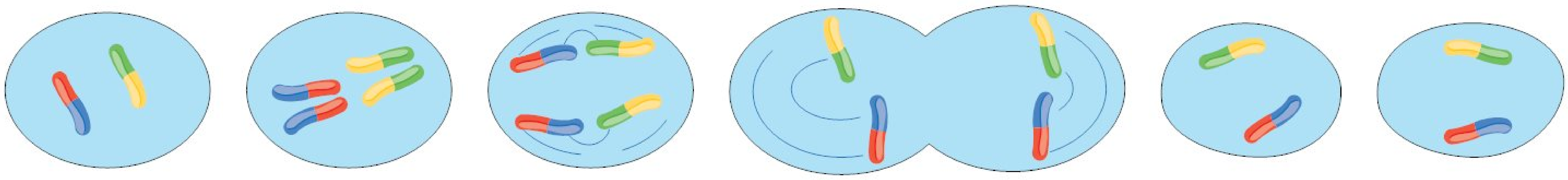
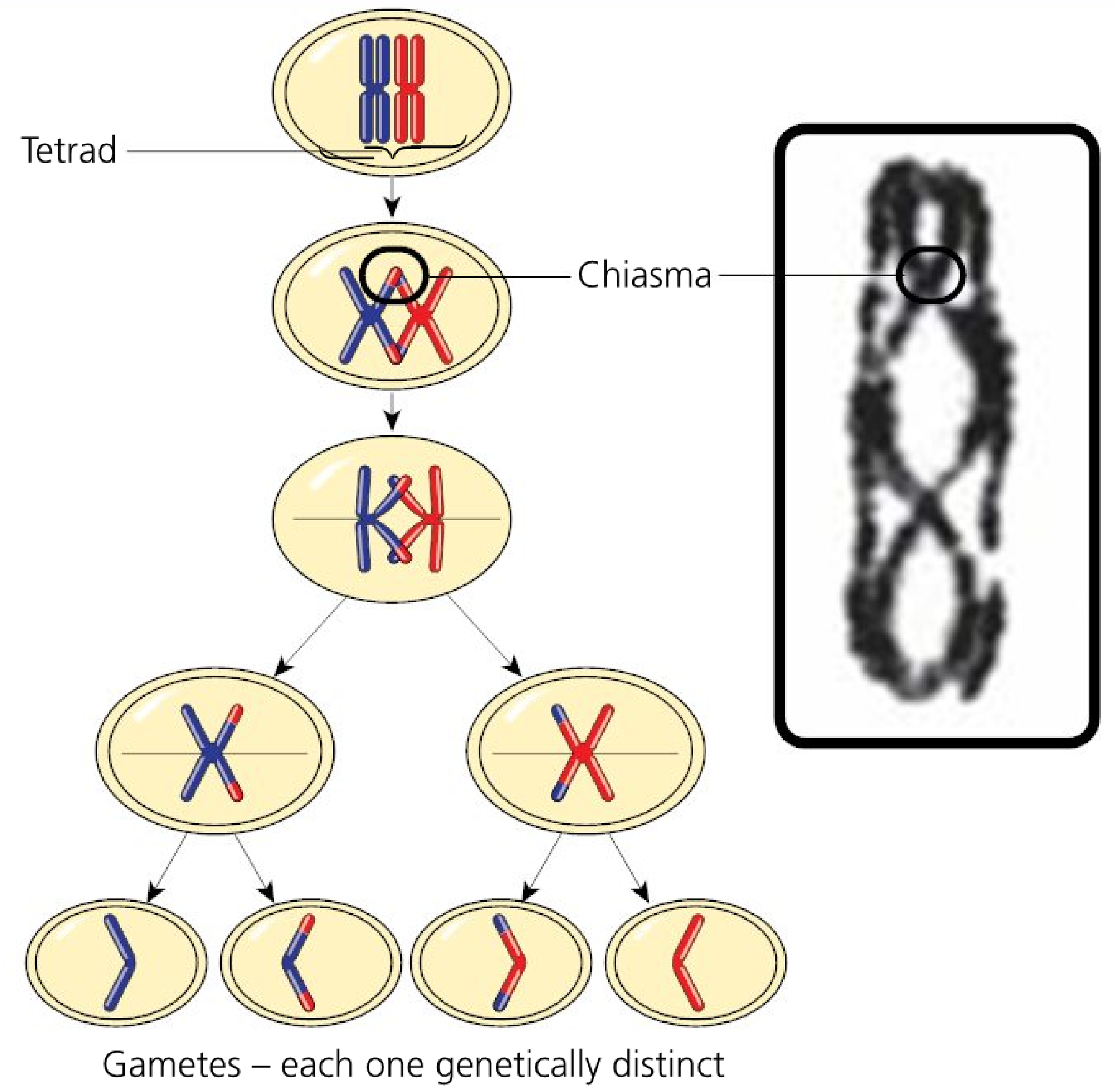


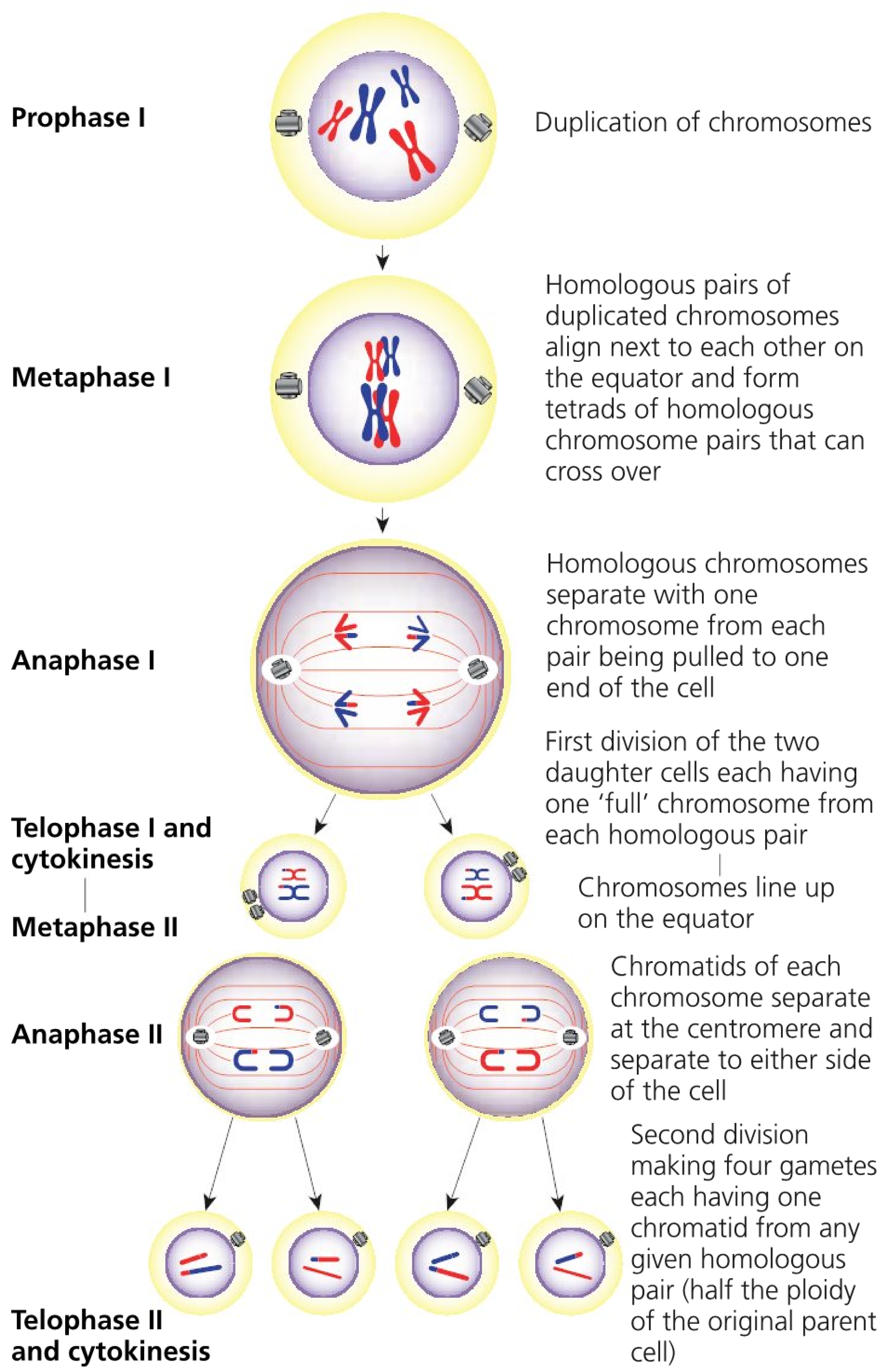
Figure 9.24 Colourful mitosis

With all its advantages, mitosis is unsuitable to produce gametes for reasons discussed before. Gametes are produced by meiosis, which results in four daughter cells, each with only half the ploidy of the parent cell. The cell division is completed in two stages: meiosis I and meiosis II. Since one of these includes duplication of chromosomes and one doesn't, this makes four haploid gametes which have different sets of chromosomes due to random separation of the chromosomes during division. This variation in the gametes helps to explain why offspring are not all the same, even if they all get half of each parent's chromosomes; each offspring is fertilized by a gamete different from the others. There is also a chance for more variation in the chromosomes distributed to the four gametes, caused by adjacent homologous chromosomes exchanging some parts in a process known as **crossing-over**. This happens at different sites, called **chiasma**. Crossing-over occurs when homologous chromosomes align next to each other in **tetrads**, or **bivalents**. This happens during metaphase in meiosis I (metaphase I) when a pair of two duplicated homologous chromosomes from each parent are arranged next to each other.

In meiosis I, the number of chromosomes is halved: during metaphase, the homologous chromosomes align next to each other in pairs (tetrads) instead of single chromosomes, which means that when the **spindle fibres** form from the **centrosomes**, they join the **centromeres** of each chromosome on either side, such that one of the homologous chromosomes from each pair is pulled to opposite sides of the cells during anaphase. So in meiosis I the pairs of chromosomes (one from the mother and another from the father) are separated, and now the two daughter cells have only chromosomes from either pair, rather than from both as in mitosis. In meiosis II, the number of chromatids is halved, so the chromosomes align as single chromosomes on the **equator** and then the spindle attaches to the centromere of each chromosome leading to the separation of sister chromatids during anaphase II. Therefore the resulting four gametes will now only have one chromatid from each homologous pair of chromosomes, making them haploid and allowing them to fuse during fertilization without doubling the ploidy.



■ **Figure 9.25** Chiasma formation and crossing over during meiosis



■ **Figure 9.26** Division stages of meiosis to form gametes

ACTIVITY: Find the mitotic index in onion root tips

ATL

- Critical-thinking skills: Use models and simulations to explore complex systems and issues
- Information literacy skills: Process data and report results
- Transfer skills: Apply skills and knowledge in unfamiliar situations

Onion root tips are used as a classical model for mitosis as they have a high rate of cell division.

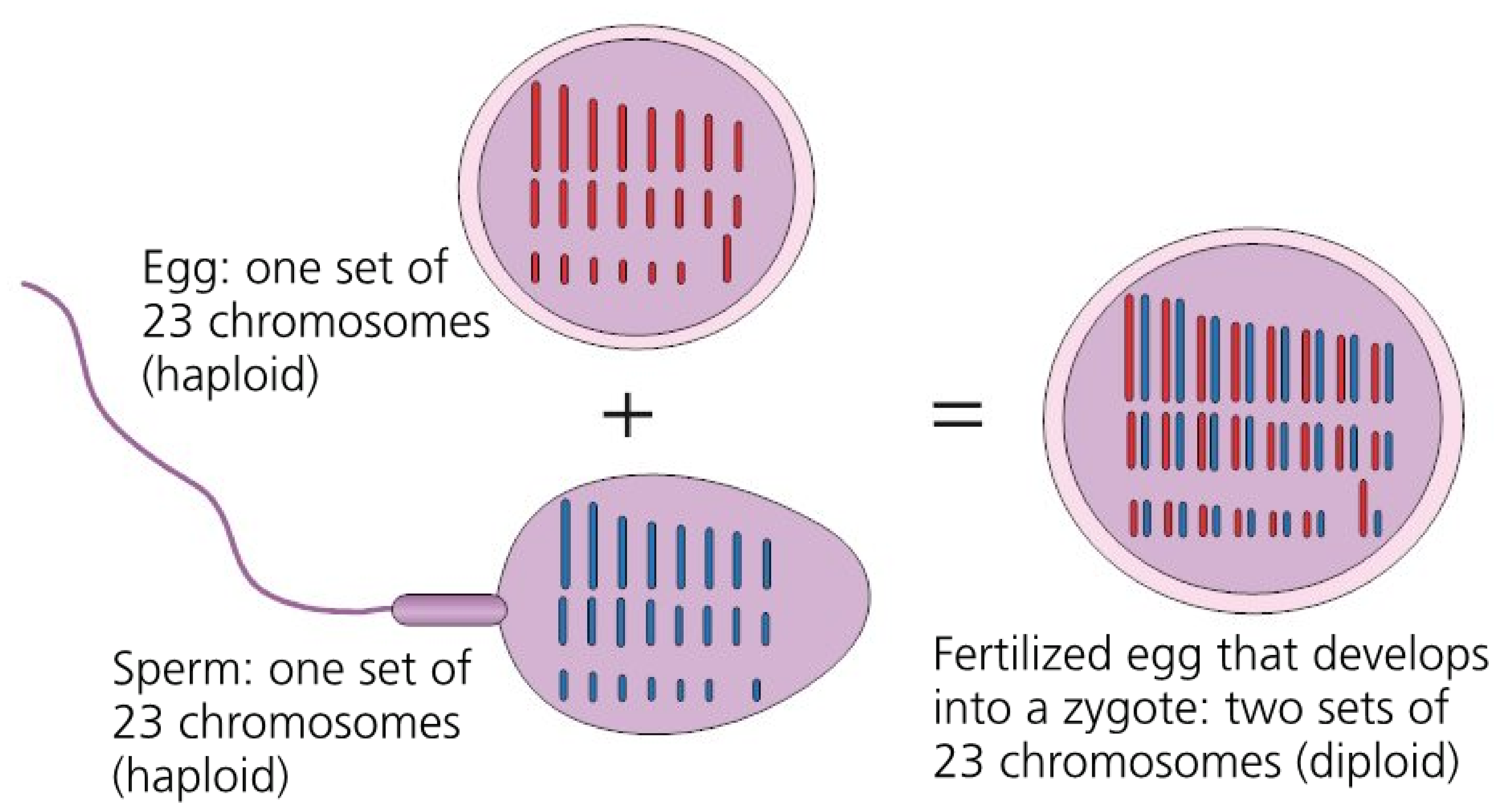
Your teacher might choose to conduct a laboratory investigation by cutting onion root tips and observing them under the microscope to see the different stages of mitosis.

Alternatively, you can use an online simulation: **www.biology.arizona.edu/cell_bio/activities/cell_cycle/cell_cycle.html**

Your task is to **design** and carry out an investigation to find the **mitotic index** in the onion tissue. Use the MYP *Sciences Inquiry Cycle* to develop your investigation and **discuss** with your teacher before you begin.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion B: Inquiring and designing and Criterion C: Processing and evaluating.



■ **Figure 9.27** Fertilization without doubling the number of chromosomes

■ **Figure 9.28** It runs in the family

HOW DO GAMETES DETERMINE THE CHARACTERISTICS WE INHERIT FROM OUR PARENTS?

SEE–THINK–WONDER

Look at Figure 9.28. What do you **see**? What does it make you **think**? What does it make you **wonder**?

EXTENSION

You can learn more about some other observable human characteristics and their possible linkage with inheritance on this website: **http://learn.genetics.utah.edu/content/basics/observable/**

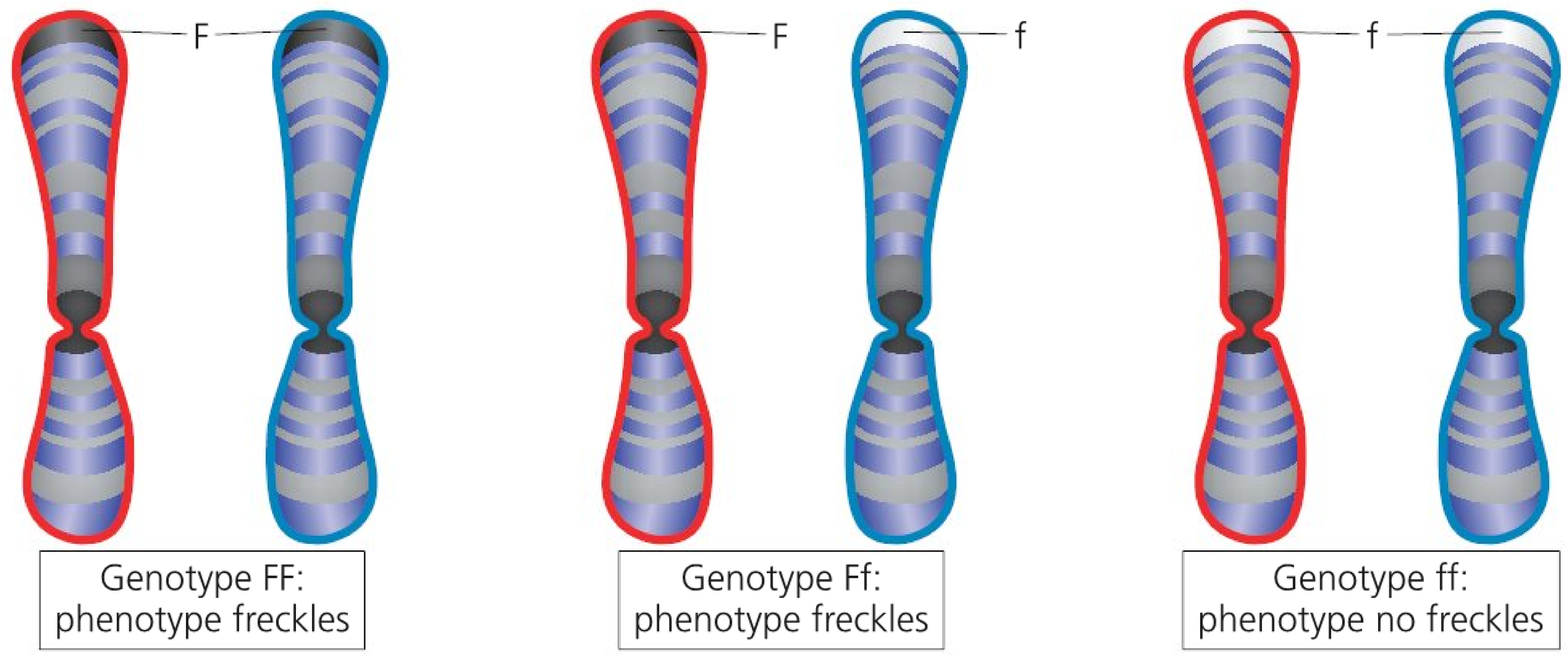
EXTENSION

Explore further: **http://learn.genetics.utah.edu/content/basics/inheritance/**

The rules of **inheritance** tell us how we inherit characteristics from our parents. More precisely, what genes were in the chromosomes that were passed into the gametes that made the zygote we developed from. The genes hold the information about every function or feature we have. Since we have pairs of each chromosome, we have two copies (alleles) of every gene.

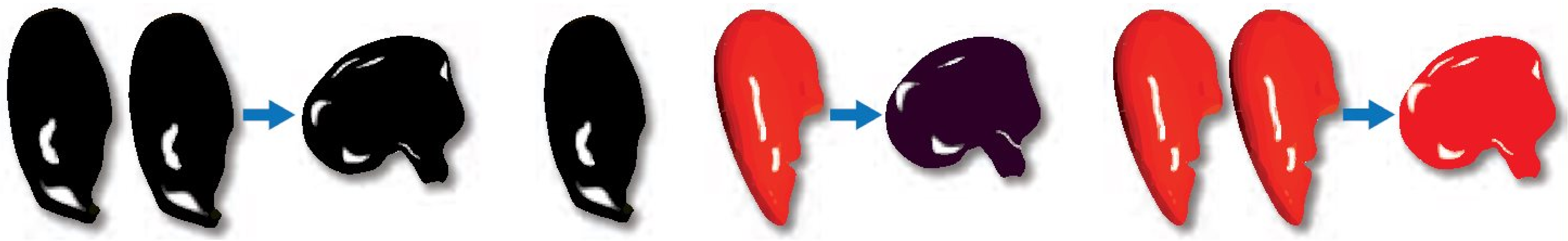
Let's take a random example called gene F. We should have two alleles for this gene that can be the same (FF) (homozygous) or they may differ (Ff) (heterozygous). This way of referring to the two alleles of each gene (FF or Ff) is called a genotype and the characteristic or trait it is responsible for is called a **phenotype**. Since the alleles are different, the phenotype that each allele is responsible for may differ too. For example, if allele F was responsible for the presence of freckles and allele f was responsible for their absence, then the FF and ff genotypes will show different phenotypes of freckles.

Dominant alleles force their phenotype to show regardless of what the other allele is and they are written in capital letters. So in our example, F is a dominant allele and both FF and Ff genotypes will show a freckles phenotype. In this case, the f allele is recessive and its characteristics are always 'masked' by a dominant second allele in a heterozygous pair. Recessive alleles will only show in a homozygous recessive allele genotype ff (no freckles phenotype). The real name of the gene responsible for freckles in humans is the melanocortin 1 receptor gene (MC1R), but freckles are also influenced by other genes and environmental factors.



■ **Figure 9.29** The alleles for genes associated with freckles are located at the same place on each copy of chromosome 16. In this diagram, the chromosome outlined in red comes from the mother and that outlined in blue comes from the father.

EXPLANATION GAME



■ **Figure 9.30** Masked or visible: shades of black

Identify something interesting in the objects: 'I notice that …'

Then ask: 'Why is it that way?' or 'Why did it happen that way?'

You can also do this exercise in a group. **State** an observation and your classmates must **explain** it. Then you can ask them again, 'What makes you think so?' In this way, each one of you is explaining their observation and their reasoning.

Relate your observations to what happens with alleles.

ACTIVITY: Do you look more like Mum or Dad?

ATL

- Collaboration skills: Build consensus
- Communication skills: Use appropriate forms of writing for different purposes and audiences; Take effective notes in class; Organize and depict information logically
- Organization skills: Create plans

We often hear: 'I got this trait from Mum or from Dad' but some are true inherited genetic traits and some are not.

Conduct a survey in your school, with those who would like to take part, to see what others think they inherited from their parents and whether they think they look more like their dad or mum. Remember, however, that not everyone is brought up by their biological parents, so you should consider the ethical impact of your survey carefully and be sensitive – allow people to opt out if they wish.

Ask questions that will help you find the inheritance of traits: ask if the siblings and other family members have the trait and whether both parents have it or just one. Do you need to consider consent in this type of research?

Collect your results and **organize** them in a table. Did you collect enough data to be analysed? **Interpret** your data. Did you find any patterns? Did more students think they looked like one parent? Did you find any repeated traits mentioned by students? Are there any traits that are more frequent?

Suggest which traits you think are recessive or dominant.

Did you find any results that you couldn't explain? This type of survey-based research is not the best way to understand inheritance of traits. If your results don't fit with your predictions, note that there are many other factors that could influence inheritance and sometimes we don't always have all the necessary information from our families.

Research and then **evaluate** your suggestions. Do your data confirm the established scientific evidence?

◆ Assessment opportunities

- ◆ In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding and Criterion C: Processing and evaluating.

EXTENSION

There are some traits in which the rules for monohybrid and dihybrid crosses don't explain the real results. Search for: **codominant inheritance, sex linked inheritance** and find out more about other inheritance methods.

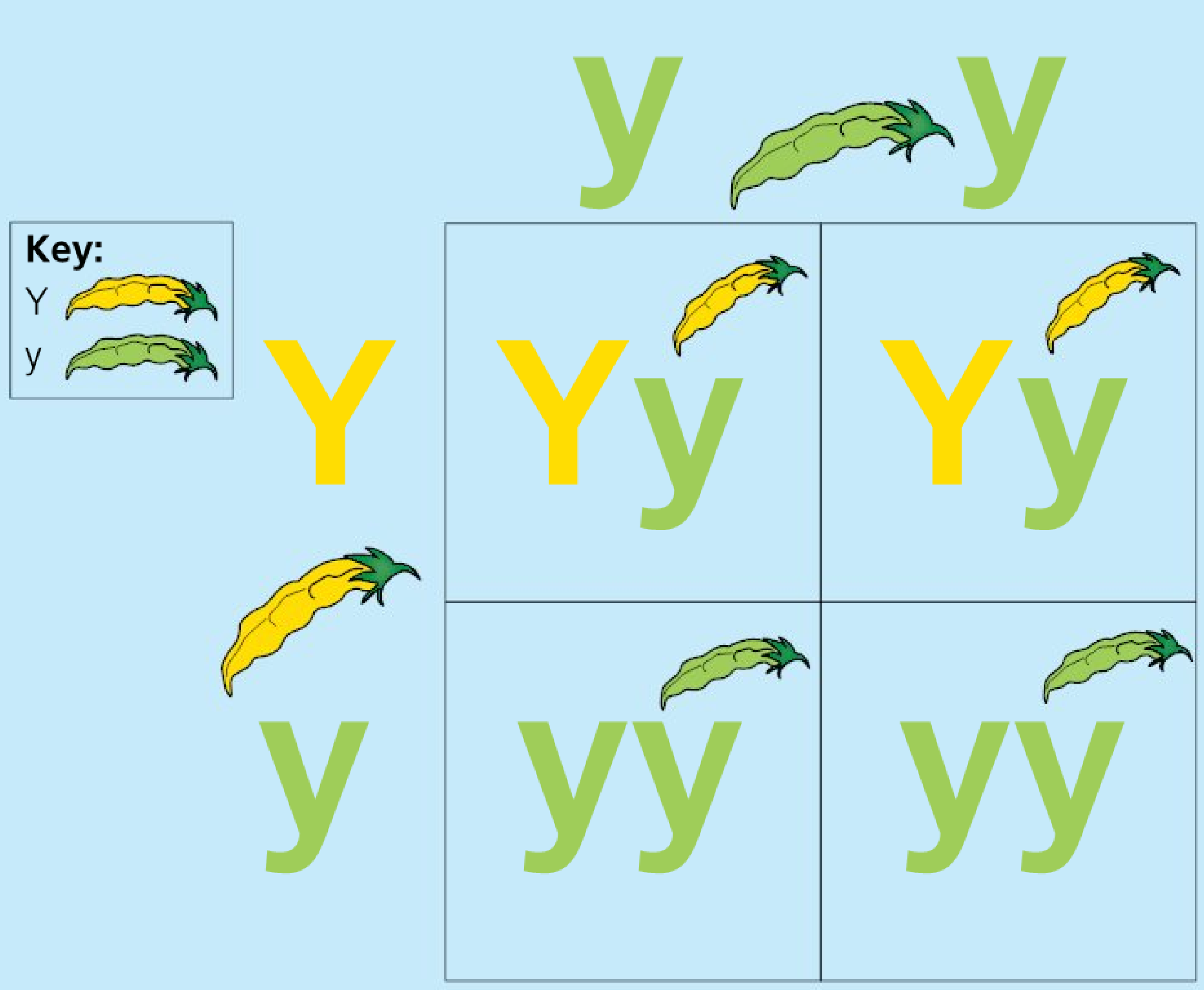
MEET A SCIENTIST: GREGOR MENDEL

■ **Figure 9.31** Gregor Mendel (1822–84)

Gregor Mendel, 'the father of inheritance', was a monk who crossed pea plants and collected the results from each cross. He kept a very large number of plants to enable him to predict the probability of results and compare them with his actual results. He was the first person to offer some explanation as to how traits are inherited. His results were not well received by the scientific community at that time and it wasn't until many years later when other scientists started reproducing his results that his work was finally appreciated. Mendel stuck to his ideas as he was sure he was correct; he was a **principled** scientist.

Mendel's pea experiments explained how traits are inherited from parents by **segregating** the alleles in each gamete. He made observations as he carried out **monohybrid crosses**, in which traits are controlled by dominant or recessive alleles in one pair of inherited alleles, or **dihybrid crosses** in the case of two pairs of alleles. Prediction of inherited alleles and phenotypes can be worked out using a Punnett grid which models the division of cells by meiosis showing one allele in each gamete. In Figure 9.32, the letter Y represents the yellow allele and the letter y represents the green allele. Crossing the yy and Yy genotypes – depending on which gamete from the top fertilizes which gamete from the side – results in different possible genotypes, and therefore phenotypes, for the offspring shown in the middle of the grid. The ratio of results should always be indicated out of the four possible combinations. Since the Yy genotype resulted in yellow phenotype and the homozygous yy genotype in green phenotype, we deduce that the yellow allele is dominant over green. The chance of gametes from the left fertilizing gametes from the top is random, so for every fertilization event in these plants there is a 50:50 chance of the peas being yellow (Yy) or green (yy).

Genotypes crossed: yy × Yy



Prediction of genotypes and ratios from possible combinations of gametes:

Genotypes:	Yy	yy
Phenotypes:	yellow	green
Ratio from the total four possible combinations:	2:4 (½)	2:4 (½)

■ **Figure 9.32** Punnett grid

ACTIVITY: Heads or tails?

ATL

- Critical-thinking skills: Use models and simulations to explore complex systems and issues; Analyse complex concepts and projects into their constituent parts and synthesize them to create new understanding
- Information literacy skills: Collect, record and verify data; Process data and report results

Conducting inheritance experiments is time consuming, so you will model tall and short pea alleles, represented by the letter T or t, using coins and **compare** the results to Punnett grid predictions.

Figure 9.33 Flip the coin

A homozygous tall plant was crossed with a homozygous short plant. All the plants in the first generation (F1) were tall plants.

Deduce which allele is dominant and **state** which allele will be represented by t and which one by T. **Determine** the genotype of the parent plants.

Construct a Punnett grid to work out the possible genotypes and phenotypes of the F1 generation and **calculate** the ratio of the genotypes and phenotypes.

When two tall plants from the F1 generation were crossed, 75 per cent of the plants in the second generation (F2) were tall and 25 per cent were short. **Explain** how short plants can result from crossing tall plants. **Construct** a Punnett grid for crossing F1 plants with each other to **explain** why 75 per cent of the plants were tall and 25 per cent were short. **State** the genotypes of the plants.

Now use two different types of coin (different colours and different sizes) to model gametes from the F1 generation plants.

One coloured coin represents the male gamete (the two sides model the two alleles) and the other coloured coin is the female gamete (two sides, two alleles).

Stick a label with a letter for each allele on each side of the coins following the Punnett grid gametes. How many times should you toss the coins to get reliable results? Remember for good probabilities, many repeats are needed. Will you toss the coins one at a time or both at the same time? Remember that you are looking at the 'chances' for any two alleles to both end up in a fertilized egg.

Flip the coins and note the genotype you get each time. **Collect** and **record** (in a table) the number of times you get each genotype. How many genotypes are possible to get from crossing the F1 generation plants? What do you notice about the number of chances for any given possible genotype? **Analyse** your results.

Evaluate your model by **comparing** the coin results to those of the F2 generation from the second Punnett grid. **Compare** your results with the known ratio for the genotypes in the F2 cross by searching: **monohybrid cross ratio F2**.

Assessment opportunities

- This activity can be assessed using Criterion A: Knowing and understanding.
- In this activity you have practised skills that are assessed using Criterion B: Inquiring and designing.

EXTENSION

Find out more about inheritance from Professor Eric Spana who has studied the inheritance of wizarding!

www.youtube.com/watch?v=8yXSQI3BFlI&t=1112s

www.livescience.com/59542-harry-potter-wizard-genetics.html

http://genestogenomes.org/inherit-the-wand/

Take action: Are you who you should be or has the environment changed you?

ATL

- Critical-thinking skills: Gather and organize relevant information
- Information literacy skills: Collect and analyse data to identify solutions and make informed decisions
- Communication skills: Use appropriate forms of writing for different purposes and audiences; Use a variety of media to communicate with a range of audiences; Participate in, and contribute to, digital social media networks; Write for different purposes

! Read the article below or some of the articles on the following websites:

www.whatisepigenetics.com/fundamentals/

www.nature.com/news/an-epigenetics-gold-rush-new-controls-for-gene-expression-1.21513

! Reflect on the information in the article. What are epigenetic marks? Are they inherited? Do they change in the course of our lives? What are mutations? Do they affect our health?

! Your school is organizing a service learning event to support a genetics organization, and you are asked to raise awareness about the impact of epigenetics on our health. **Summarize** your research and **organize** your information on epigenetics to inform different audiences using different ways of presenting information (posters, assemblies, articles to be posted on your school's social media page).

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

Epigenetic factors (also known as epigenetic marks or tags) modify the histone proteins associated with the DNA in many ways such as methylation and acetylation (adding methyl and acetyl tags, respectively). Such modification of the proteins affects the way they work, changing some functions like gene expression and whether some genes are turned on or off. Such control of when genes are expressed is important for normal growth of the body during development and **cell differentiation**, but is also associated with some diseases. For example, some genes that work to protect against cancer can be turned on or off when they shouldn't be, increasing the risk of developing various complex diseases including cancers, obesity and autism. Epigenetic marks are affected by the environment and accumulate during a person's life (for example two identical twins will have different epigenetic marks as they grow up), but some of these marks can be passed on from parents.

Throughout a person's life, epigenetic changes to genes build up, making it more or less likely over time that certain genes will switch on or off. The build up of epigenetic changes is part of normal aging. However, this build up may also increase the likelihood that certain genes will be changed in a way that leads a person to develop age-related diseases, such as cancer and diabetes. Many diseases are caused by a combination of different types of changes in many different genes. Some of these changes are genetic **mutations** that are passed along in families. Some are mutations that happen randomly or because of environmental factors. And some are epigenetic changes caused by environmental or other factors. Many diseases and conditions are linked to epigenetic or developmental epigenetic changes. So far, scientists have been able to link the following diseases to epigenetics: obesity, heart disease, various cancers. autism, fragile X-syndrome (an intellectual disability), Angelman syndrome, Prader–Willi syndrome, Beckwith–Wiedemann syndrome (a congenital growth disorder), Rett syndrome, Rubinstein–Taybi syndrome (a rare intellectual and developmental disorder) and Coffin–Lowry syndrome (another rare genetic/epigenetic disorder). It is important to note that the above list of diseases is only partial; almost any complex disease is likely to be caused, in part, by epigenetic changes. Scientists are just now starting to uncover the specific changes that contribute to all the various diseases.

How can heredity go wrong?

Gene mutations in DNA can lead to different amino acids being translated, which in turn may change the structure and function of the entire protein. Mutations can happen when DNA replicates during cell division, but can also be induced by other **mutagens** such as chemicals or ionizing radiation. These acquired mutations may cause permanent changes to phenotypic traits due to the permanent change in the gene and may cause diseases like **cancer**. Some **single point mutations** can be caused by a deletion or addition of a single base in the DNA, or a substitution of one base with another as in **sickle cell anemia**. **Germline mutations** carried in the gametes are hereditary and will be passed on during sexual reproduction to the offspring. **Chromosome mutations** are caused by mistakes in the separation of chromosome tetrads during meiosis I or by **nondisjunction** when sister chromatids fail to separate in meiosis II, as in the case of **Down syndrome**. As shown above, mutations can be disadvantageous and cause disease. However, sometimes they can be advantageous and add beneficial characteristics, for example some mutations make viruses or bacteria resistant to drugs and antibiotics. In humans, a mutation that causes a deletion of 32 bases in the **CCR5 gene** increases resistance to **HIV** or delays its progress to **AIDS**, depending if the mutation is homozygous or heterozygous, respectively. Sometimes, mutations don't benefit or harm the organism. They just introduce variation in the genes.

ACTIVITY: Listen–modify–transmit!

ATL

- Creative-thinking skills: Generate metaphors and analogies; Apply existing knowledge to generate new ideas
- Critical-thinking skills: Analyse complex concepts into their constituent parts and synthesize them to create new understanding

Write the same two sentences on two different pieces of paper. Keep one and pass the other to your classmate who is asked to change a maximum of one word in the text (they may not change anything) and rewrite the text (even if no change was made), then pass it to another student. Repeat this process with the whole class.

The last student should read the text they received. Has the meaning changed?

Discuss how this game might relate to mutations. Why did you give your classmates the chance to change or not change a word? Do mutations happen at every generation?

Explain why you compared the meaning of the sentence and not the exact words. Do DNA mutations always lead to changes in proteins?

If the words in your sentence changed without changing the meaning, you found another way of saying the same thing! How does this relate to mutations? Is it good to change some genes without changing the proteins? Link this to variation, diversity and evolution of species.

ACTIVITY: Inheriting 'some' bad genes is not always all that bad!

ATL

- Information literacy skills: Process data and report results
- Communication skills: Organize and depict information logically

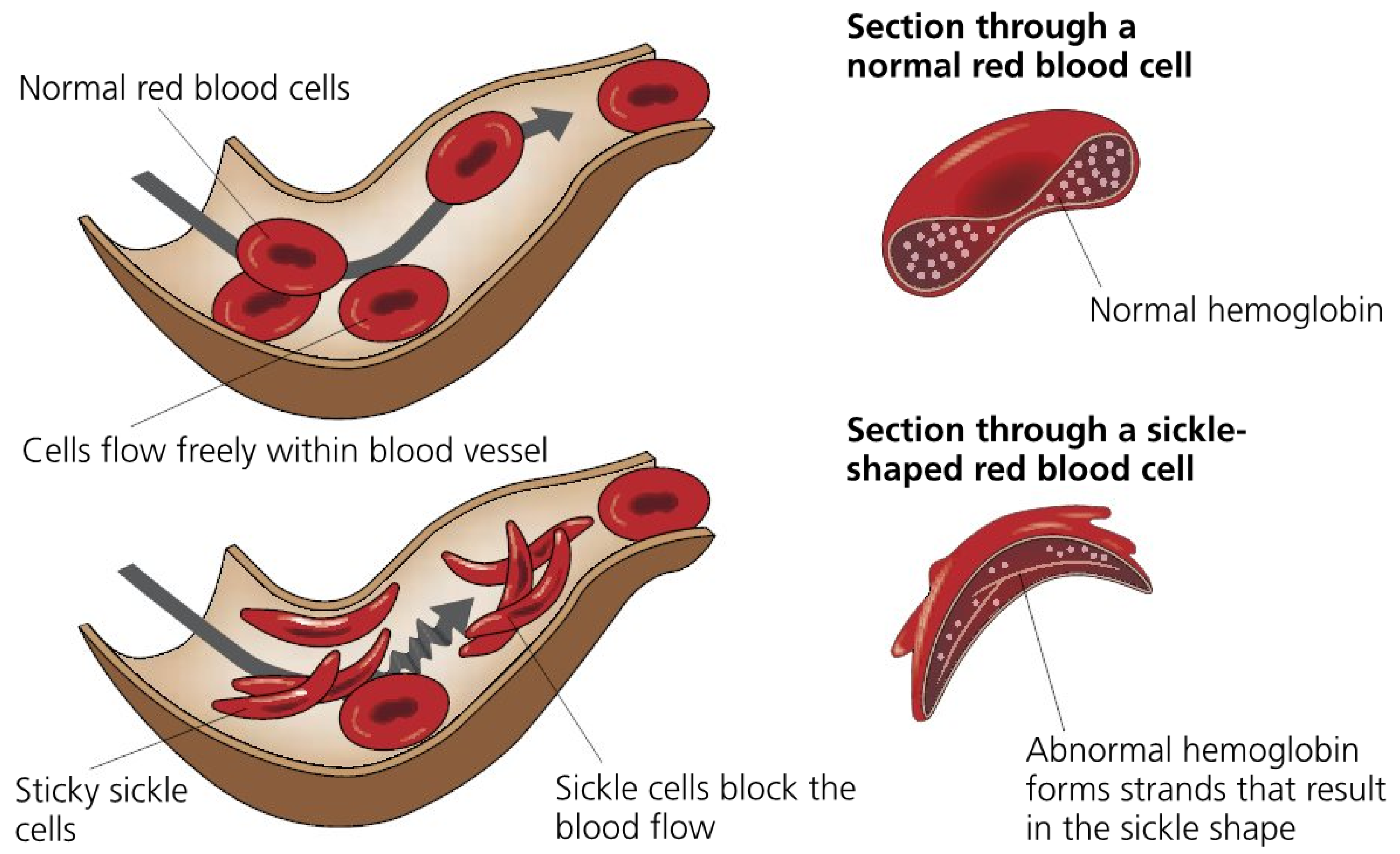


Figure 9.34 Sickle cell anemia

Sickle cell anemia is a genetic disease caused by a single base substitution in the DNA of the hemoglobin gene (Hb). It damages red blood cells, making them crescent shaped which blocks small capillaries, reducing oxygen transport and leading to severe anemia (Figure 9.34). The Hb gene has two alleles: the Hb^A and the Hb^S alleles. Different combinations of these alleles show different phenotypes:

Hb^AHb^A: **healthy** phenotype

Hb^AHb^S: **carrier** phenotype with **sickle cell trait**: shows anemia symptoms but not sickle cell anemia

Hb^SHb^S: **sick** phenotype with **sickle cell disease**

There is a hidden advantage of sickle cell anemia that is related to **malaria**. Evolution favours alleles which give a survival advantage. Reflect on the advantage that sickle cell anemia may give against malaria and **suggest** which genotype you think will give such an advantage. **Justify** your answer.

Look at the data presented to you in Table 9.6:

Age range/ years	Genotype	Number of participants	Crude malaria incidence
All	Hb^AHb^A	892	1.74
	Hb^AHb^S	162	1.07
0.25–2	Hb^AHb^A	302	1.99
	Hb^AHb^S	52	1.52
2–4	Hb^AHb^A	417	2.12
	Hb^AHb^S	73	1.45
4–6	Hb^AHb^A	423	2.18
	Hb^AHb^S	81	1.28
6–8	Hb^AHb^A	361	1.88
	Hb^AHb^S	82	0.94
8–10	Hb^AHb^A	275	1.61
	Hb^AHb^S	62	0.66
≥10	Hb^AHb^A	283	0.96
	Hb^AHb^S	48	0.67

Table 9.6 Association of sickle cell anemia with malaria incidence

- **Plot** a graph showing the incidence of malaria for the different age groups. **Analyse** your results.
- **Construct** a new table to reorganize the data to show the relationship between the AA and AS genotypes and the incidence of malaria.
- What do you notice? **Analyse** the results referring to the data.
- Is there any correlation with the age of participants? **Justify** your observations with the data.
- Some groups have a larger number of participants than others. How could this influence the data? Could this difference be compensated by other groups with the same genotype? **Justify** your answer with the data.
- **Analyse** the first two rows showing the pooled data from all age groups and **compare** all the points mentioned above to make a generalized analysis about the two genotypes. **Evaluate** your data and **discuss** any exceptions.

Assessment opportunities

- This activity can be assessed using Criterion C: Processing and evaluating.

Take action: Are we mutating the fish?

ATL

- Critical-thinking skills: Gather and organize relevant information
- Information literacy skills: Collect and analyse data to identify solutions and make informed decisions
- Communication skills: Use appropriate forms of writing for different purposes and audiences; Use a variety of media to communicate with a range of audiences; Participate in, and contribute to, digital social media networks; Write for different purposes

! What is the impact of chemicals present in the waste we discard in the sea on organisms of the aquatic ecosystems?

! Read the following articles. What is happening to humans?

www.independent.co.uk/environment/environment-fish-changing-sex-gender-chemicals-pollution-rivers-water-charles-tyler-fisheries-a7821086.html

www.naturalnews.com/052832_atrazine_endocrine-disrupting_chemicals_sex_changes.html

! You work for an environmental agency and you want to raise awareness of the impact of chemicals that get thrown in the water on aquatic wildlife.

! Write a news article on this environmental issue and the possibility that it may affect humans. Make your story attention grabbing, as it may be read by people who could make an impact in making some changes. Be concise and informative. You may make a difference!

! Record a short video summarizing your argument and post it on a social media platform. It may be seen by thousands or millions of viewers.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion D: Reflecting on the impacts of science.

Should we modify the genetics of living things?

SEE–THINK–WONDER

Papaya fruit can be infected by a deadly virus (ringspot virus) that damages the crop and causes loss to farmers. Look at Figure 9.35. What do you **see**? What does it make you **think**? What does it make you **wonder**?

WHAT IS GENETIC MODIFICATION? WHAT IS IT FOR?

■ **Figure 9.35** To modify or not to modify: that is the question! (a) Papaya infected with ringspot virus. (b) GM papaya resistant to the virus.

ACTIVITY: 3–2–1 BRIDGE

Would you keep your old phone if you could upgrade it to one with better features? Would you 'upgrade' your food to get better nutrients?

In this activity you will compare upgrading your phone to upgrading your food by **genetic modification** (GM).

Copy and complete Table 9.7 and work in groups to find

- **3 thoughts or ideas related to each situation (what upgrades can you make to your phone or food to make them better?)**
- **2 questions about this issue**
- **and finally 1 analogy. Share your ideas with the class.**

	Familiar situation (phone)		Unfamiliar situation (crops)
3 thoughts/ideas			
2 questions		**BRIDGE** Upgrading a phone is similar in a way to upgrading food because it allows …	
1 analogy	'an upgraded phone is like …'		'upgraded food/crop is like …'

■ **Table 9.7** 3–2–1 bridge: upgrade your phone vs upgrade your food

PEEL THE FRUIT!

ATL

- Critical-thinking skills: Draw reasonable conclusions and generalizations; Analyse complex concepts and projects into their constituent parts and synthesize them to create new understanding

Make your final additions to the 'peel the fruit' understanding map which you started at the beginning of this chapter. You have now reviewed many complex concepts: genetics, cell division, mutation, reproduction, inheritance and GM. Try to link them all together. Add your deepest understandings to the core of the map, highlighting the connection between all the concepts.

The genetic material in GM crops has been manipulated using different methods in order to make it more useful to humans. Modifications can include improving resistance to a disease (e.g. rainbow papaya), improving nutritional content for use in countries with poorer diet (e.g. golden rice) or making a crop more resistant to arid growing conditions (e.g. salt-resistant tomatoes).

EXTENSION

Find out more about GMO on the NCBI Pubmed website: **www.ncbi.nlm.nih.gov/pubmed**

Search for: **genetically modified plants and human health, genetically modified food**.

Consideration of ethics in science

Scientific innovation brings about change and change raises new ethical questions. Scientists consider ethics carefully and are often regulated by government agencies that are charged with monitoring innovation and adhering to ethical guidelines. For example, in many countries research institutions cannot experiment on GM unless they obtain a license from a relevant government agency in their country. The government agencies carry out regular checks on research institutions and hold the right to stop any work that does not follow their stringent requirements.

There is no doubt that GM has improved our health and living conditions in many ways. However, there are still many questions and there is scepticism associated with GM, especially if it falls into careless hands.

! Take action: Question starters: the future of GM

ATL

- Critical-thinking skills: Formulate factual, topical, conceptual and debatable questions

Will we stop mating and start cloning?

Will we be able to design our babies?

Could extinct animals be brought back to life?

Could GM animals destroy ecosystems?

Could GM plants take over?

Hemophiliacs' lives transformed by GM milk

Modified crops are hardier and can save lives

GM clone tissue can heal better

Insects given super-powers to combat pests

! The black headlines above are questions people have posed about GM. The white headlines are real applications of GM used to improve lives.

! In pairs, **discuss** one positive and one negative headline with your partner. **Suggest** whether fears about GM are justified. **Share** your ideas with the class.

! Now use what you have learnt in this chapter to think of and speculate about possible future applications of GM. What positive possibilities could it offer? Use the following question starters to write your questions on sticky notes and stick them on the wall:

- How would it be different if ...? Why ...? What would change if ...? What are the reasons ...? Suppose that ...? What if ...? What is the purpose of ...? What if we knew ...?

! **Discuss** your questions as a class.

What is ionizing radiation? What determines the effect of ionizing radiations on matter?

One important cause of genetic change – both natural and artificial, beneficial and malign – is radioactivity. In the next section we will explore how radioactivity works and how ionizing radiations interact with living and non-living matter.

We saw in Chapter 2 how atoms are described in terms of elementary particles as building blocks, and in Chapter 3 we found that atoms of the same element may occur as different isotopes with different numbers of neutrons. The more scientists discovered about atoms, the more they realized that the nucleus was neither so solid nor so simple as had been thought. Nuclei are in a constant state of energetic excitation; it is better to imagine them as wobbling, vibrating clumps of matter. Occasionally, the energy of these vibrations may overcome the short-range strong nuclear force. When this occurs, bits of the nucleus are released, carrying away some of the nucleus's energy in fixed amounts. This process is known as **decay**. The nucleus then 'relaxes' to a lower energy state and if the resultant nucleus is a more stable configuration it may even stay that way. On the other hand, there is no guarantee that the new state will be stable, so another decay may occur.

Any bits of matter ejected from the nucleus are highly energetic and electrically charged. This is why they tend to **ionize** any matter they encounter. For this reason, the mysterious rays are better termed **ionizing radiations**. This ionization can cause further changes, especially when the matter concerned is biological, in which case the radiation can cause damage to cells.

Alpha (α) **particles** consist of a very stable configuration of two neutrons and two protons bound together. This corresponds, in fact, to the configuration of a helium nucleus.

$${}^{4}_{2}\alpha$$

To find out what is produced when an alpha decay occurs, we have to subtract out the proton and nucleon numbers of the alpha particle from the decaying nucleus:

$${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha$$

Note that the new nucleus, Y, is now a completely different element.

In addition to the kinetic energy carried by the alpha particle, some additional energy E is often released. This energy is usually very high frequency, corresponding to the gamma-ray part of the electromagnetic spectrum and so **gamma** (γ) **radiation** is produced. Note that gamma radiation is *not* a particle in the usual sense, but a wave.

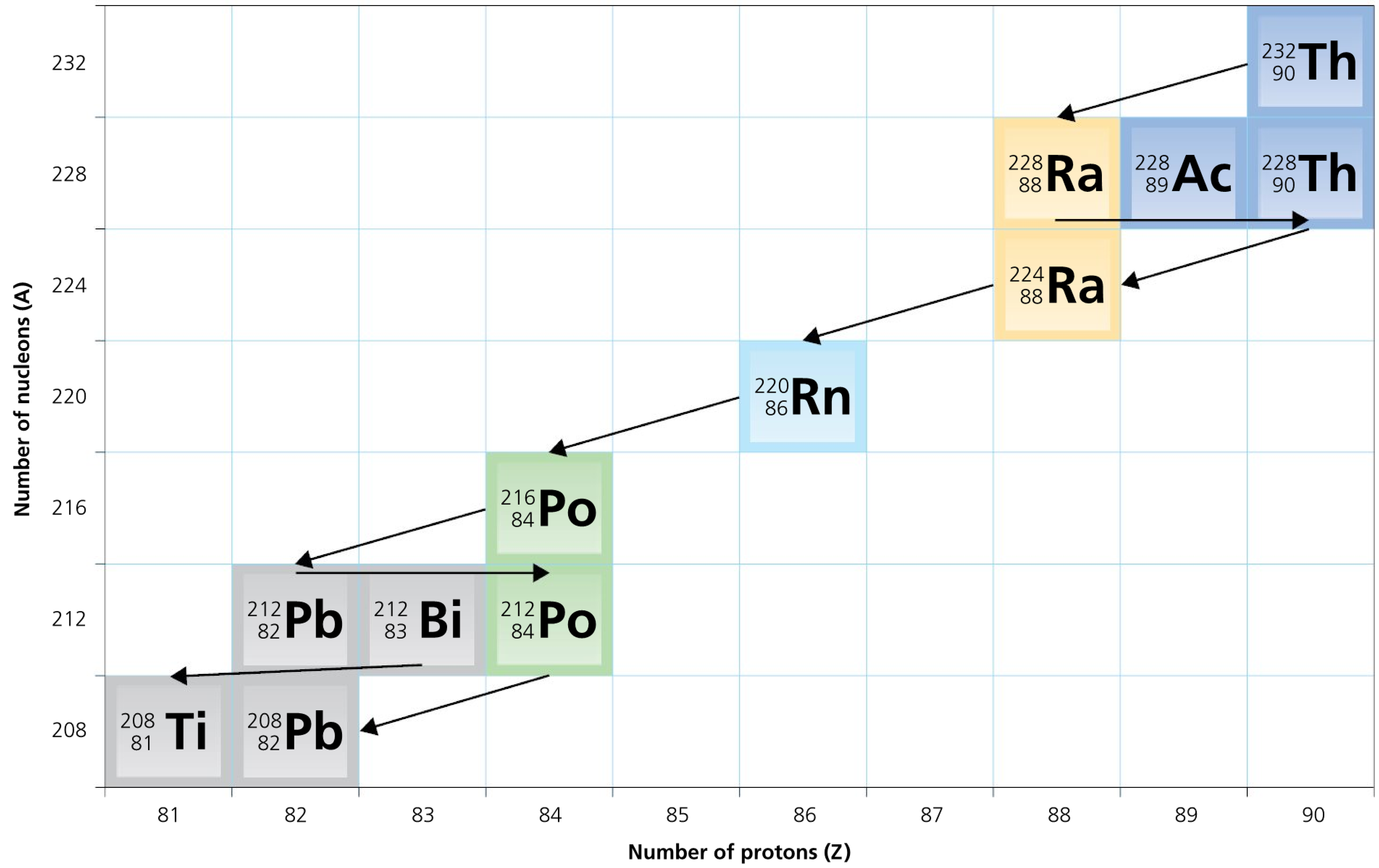
Another common form of ionizing radiation is called **beta** (β) **radiation**. This is still more exotic, since it corresponds to a fast electron that has been emitted from the nucleus. This should seem immediately counter-intuitive, because after all there *are* no electrons in the nucleus. In fact, it turns out that neutrons can themselves decay to form a proton and an electron and the excitation energy released in the process is carried away by the beta particle and another particle, called an **anti-neutrino**.

$$n^0 \rightarrow p^+ + e^-$$

$${}^{A}_{Z}X \rightarrow {}_{Z+1}^{A}Y + {}^{0}_{-1}e + \bar{\nu}$$

Notice here that the mass number A for the new nucleus Y stays the same, since we have simply exchanged a neutron for a proton, while the proton number increases by one.

The anti-neutrino is a very exotic particle indeed; it carries no charge and has almost negligible mass. It is an example of an **antimatter** particle that we met in Chapter 2. It does not usually cause any further interactions, so the effect of beta decay is restricted to the ionization caused by the beta particles.



■ **Figure 9.36** Stages in the decay of thorium showing the different elements produced

EXTENSION

Can you deduce the types of decay taking place in Figure 9.36?

ACTIVITY: Cannonballs and mosquitoes – comparing properties of radiations

ATL

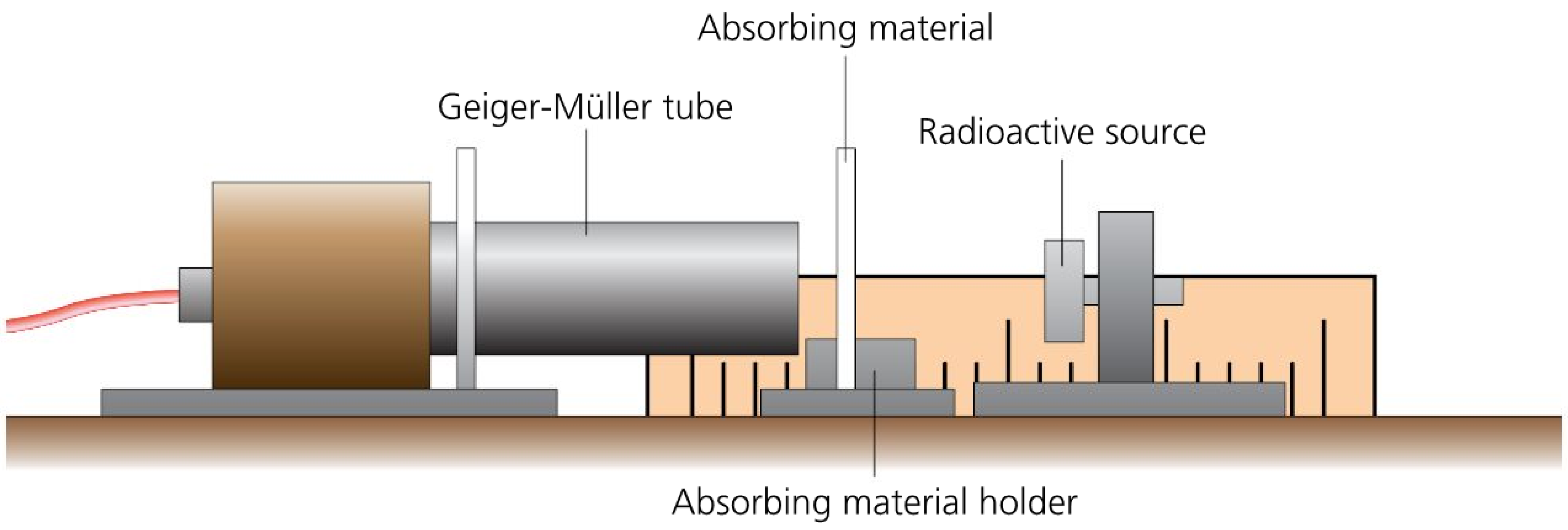
- Critical-thinking skills: Interpret data; Draw reasonable conclusions and generalizations

Apply what you already know about atomic particle masses and electric charges to complete the first two columns of a copy of Table 9.8.

In this activity you will **compare** the penetration of different ionizing radiations and **explain** the results by **applying** what we have learnt about their composition.

Radiation	Mass/*u*	Electrical charge/*e*	Penetration	Ionizing effect
alpha				high
beta				moderate
gamma				low

■ **Table 9.8**



■ **Figure 9.37** Set-up for radiation absorption experiment

Figure 9.37 shows apparatus for comparing the penetrating effects of alpha, beta and gamma radiations.

In the experiment, three different radioactive elements are used as sources of radiation. The radiation is detected using a Geiger–Müller tube connected to a counter. The Geiger–Müller tube produces a current flow every time an ionizing particle enters it and the counter counts the number of current 'pulses'.

Vibin and Kohei carry out a series of three experiments for each of three radioactive sources. The sources are

- **americium-241, $^{241}_{95}Am$**
- **strontium-90, $^{90}_{38}Sr$**
- **cobalt-60, $^{60}_{27}Co$.**

In the first experiment, they measure the number of counts for 10 seconds at different distances from the detector.

In the second experiment, they measure the number of counts for 10 seconds as they insert sheets of aluminium between the detector and the source.

In the third experiment, they do the same as the second, but they use sheets of lead.

Write a hypothesis about what Vibin and Kohei should observe in their experiments. **Explain** your predictions using what you have learnt about ionizing radiations.

If your school allows the use of radioactive sources, your teacher may demonstrate the experiment in action. Alternatively, your teacher will give you a table of results gathered by Vibin and Kohei.

Present Vibin and Kohei's data in a form that allows for comparison of the radioactive sources.

With reference to the data and any research of your own about the radioactive sources, **identify** the ionizing radiations produced by each of the sources and **explain** the differences in their results.

Was your hypothesis correct?

Evaluate the procedure in the experiment with reference to Vibin and Kohei's results. **State** any assumptions they may have made. **Suggest** how they might have improved the accuracy or the validity of their results.

◆ Assessment opportunities

- ◆ In this activity you have practised skills that are assessed using Criterion C: Processing and evaluating.

In the investigation in Figure 9.37, the experimenters start out by taking a count when no source was present; the **background radiation**. While ionizing radiation can be very damaging to biological tissue, it is nevertheless present in the environment all around us. Certain rocks contain relatively high concentrations of radioactive nuclei, and some of the radiation received from the Sun makes it to the ground. We are even bathed in radiation from distant stars in our own galaxy! In fact, we owe our existence to background radiation. One effect of ionizing radiation is to change or damage the structure of genetic molecules such as DNA.

As radioactive nuclei decay, they transform into new substances which may or may not themselves be radioactive. With time, the amount of the original substance diminishes. However, we have also seen that radioactive decay is unpredictable; there is no way to predict when the excitation energy of a particular nucleus will lead to decay. It would seem, therefore, that it would be very hard to deduce how much of a particular substance we might expect to find in a radioactive sample.

The radioactivity of a sample of material will depend on the number of radioactive nuclei it contains. In turn, this means that the rate of decrease of the number of nuclei, N, will depend on the number, N, there are. We can write this relationship as a simple equation:

$$-\Delta N(t) \propto N$$

where the delta symbol (Δ) means 'change in' the number of particles N, and (t) indicates time. (Note that the proportionality symbol, $\propto$, is not the same as the symbol for alpha, α.)

If the rate of decay depends on the number of nuclei remaining, what will happen to the rate as time goes on?

ACTIVITY: The decay game

ATL

- Critical-thinking skills: Use models and simulations to explore complex systems and issues

In this activity we are going to investigate radioactive decay using a simple model with dice.

Equipment

- **Minimum 30 dice (or more)**
- **Large container for shaking dice**
- **Pencil and paper**

Method

1. **The dice will represent the radioactive nuclei. Choose a number that will indicate when an individual nucleus has 'decayed'.**
2. **Shake all the dice in the container.**
3. **Remove any dice that have decayed – that is, fallen with your chosen number. Place these dice to one side.**
4. **Note down the number of decayed dice.**
5. **Repeat until all dice have decayed.**

Results

Organize your results in a suitable table showing number of dice remaining, turns and number decayed.

Now **plot** your results on a graph to show how the number of dice decreased.

Analysis

On your graph, **show** the points at which the number of dice halved, whether an integer or not. So, if you began with N dice, find the points corresponding to $\frac{N}{2}$, $\frac{N}{4}$, $\frac{N}{8}$, and so on.

Now trace across to **show** the number of turns, T, at which each of these numbers was reached.

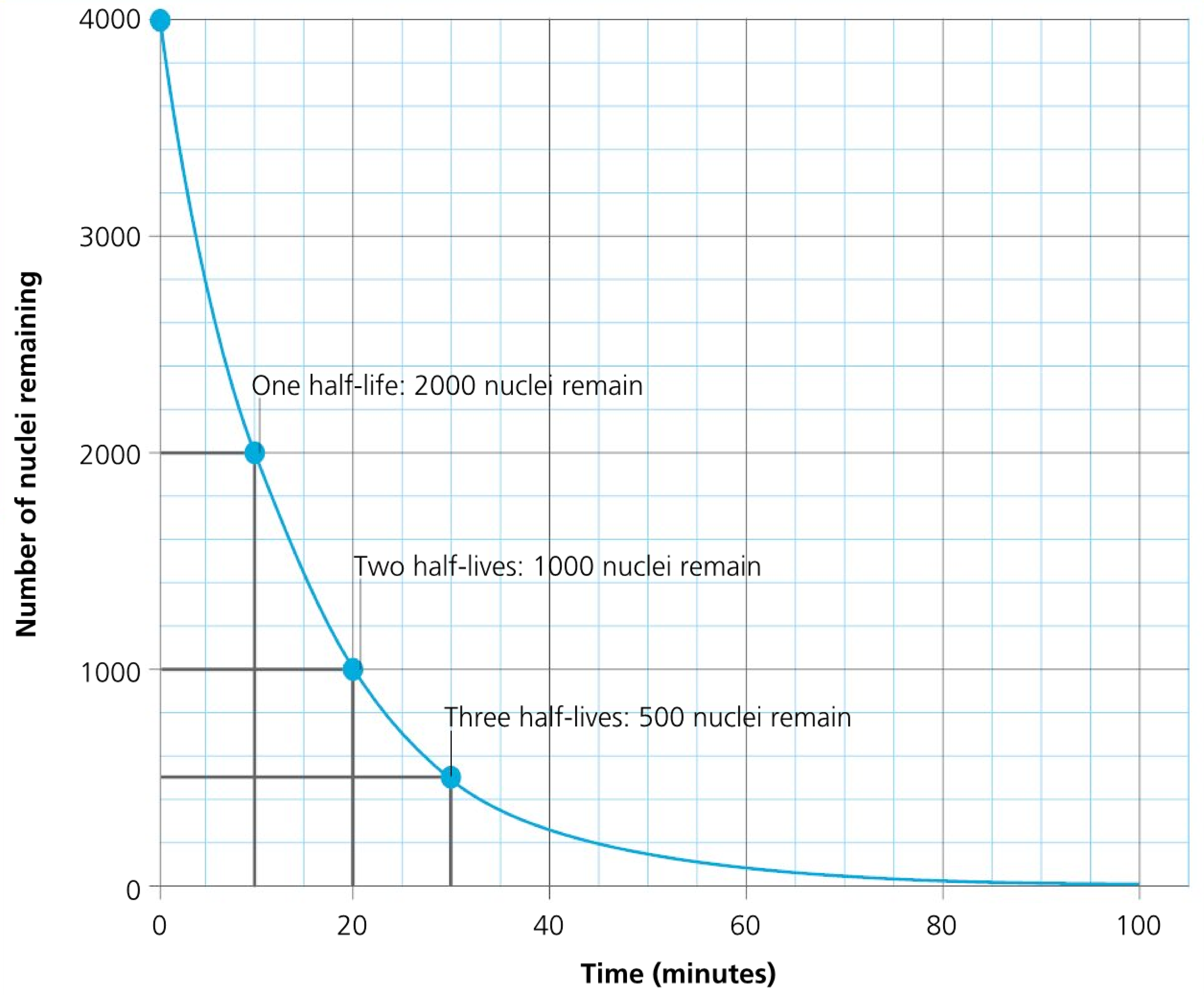
What do you notice about the intervals between each of the number of turns you found?

EXTENSION

It may be possible to obtain dice with different numbers of sides from role-play gaming shops. Repeat the game with different dice.

Outline how changing the number of sides on the dice would affect the decay curve.

How can we use ionizing radiations?



■ **Figure 9.38** Half-life decay curve

The decay curve (Figure 9.38) has some interesting properties.

- The gradient of the curve decreases in proportion to the number of the original nuclei, N, remaining.
- The time taken for the number of nuclei to reduce to a half of its value remains the same each time. This time is known as the **half-life** of the radioactive nucleus.

Half-life is a useful quantity since it relates to the stability of radioactive nuclei and it tells us how much of the nucleus to expect at a given time.

Radioactive isotope	Decay type	Half-life
uranium-238	alpha	4.5×10^{19} years
carbon-14	beta	5730 years
iodine-131	beta	8 days
polonium-214	alpha	0.00016 seconds

■ **Table 9.9** Sample half-lives for radionuclides

One very useful application of the half-life relationship is in **radiocarbon dating**. In Table 9.9, you can see that there is an isotope of carbon called carbon-14 which has a half-life of 5730 years. Carbon-14 makes up about 0.000 000 0001 per cent of all the carbon in the environment. In other words, about one carbon nucleus in a trillion is carbon-14! Carbon-14 undergoes beta decay. Since it is present in the environment, it is absorbed and expelled by living things in, for example, carbon dioxide gas. While the organism is alive, the amount of carbon-14 it contains will remain about constant. However, when the organism

Links to: Mathematics

Exponentials

The radioactive decay curve is an example of a very powerful *mathematical* tool. While the term 'exponential' refers more generally to any power term in an equation, such as n^x, it is most often used to describe a function in which a variable's rate of change depends on the value of the variable itself. Compare this to *logarithmic scales* as we saw in Chapter 6 when discussing pH.

dies, its carbon content is trapped within it. The carbon-14 component will decay. Thus, by measuring the amount of beta radiation coming from the remains of an organism, knowing that the time for half of the carbon-14 to decay is 5730 years, we can estimate how long it has been dead.

The Turin Shroud is one famous example where radiocarbon dating was used. The shroud is alleged to be the linen shroud in which the body of Jesus Christ was wrapped after the crucifixion. Since linen is made from cotton, it could be dated. Radiocarbon dating of a tiny part of the shroud in the 1980s suggested that it was in fact only around 400 years old and so probably a medieval fake. However, controversy has recently returned since it has been claimed that the linen used in the tests was a medieval patch to repair fire damage!

Figure 9.39 The Turin Shroud

ACTIVITY: Useful radiation

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument
- Information literacy skills: Access information to be informed and inform others

Radioactivity has many uses: commercially, in engineering and technology, and in medicine.

Choose one of the uses of radioactivity from this list:

- **Fire and smoke detection**
- **Medical imaging**
- **Medical interventions – cancer treatments**
- **Archaeology**
- **Food preservation**

Identify a specific technological application in your chosen area.

Describe the problem that the application solves and **explain** how radioactivity is used in the application.

Discuss and **evaluate** the use of radioactivity for this application. Are there other ways of solving the problem? **Compare** to the use of radioactivity, identifying important factors such as cost, health issues, environmental issues and cultural questions.

Figure 9.40 Radiation in use

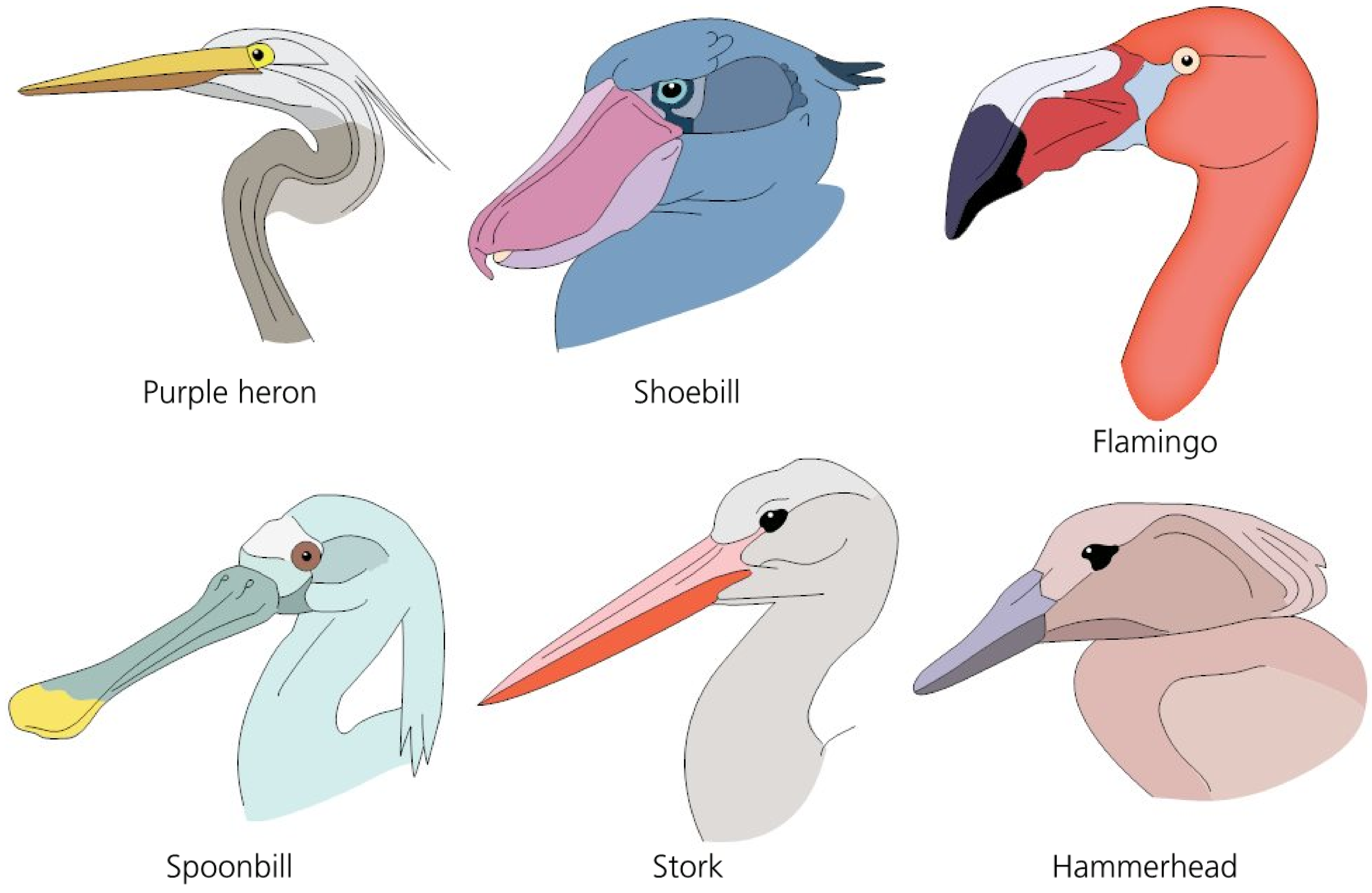
Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

While we can see that radioactivity can be used in many ways that are beneficial to humanity, its reputation as 'harmful science' is not without foundation. You may have seen in the activity *Useful radiation* how radiotherapy is used to destroy cancer cells, but it does not restrict its effect to cancerous cells and can also damage the DNA in healthy cells. The effect of radiation is similar to that of other environmental toxins that can affect genetic make-up, as we saw earlier this chapter: it causes random mutations that lead to changes in the organism. These changes can often be inherited.

When those changes are beneficial to the organism, it may be because they help the organism survive under new conditions or find new food sources. For example, a mutation that leads a wading bird to develop a slightly longer beak might mean the bird can reach more worms in the sand of a beach. The bird is then more likely to survive and as a consequence will pass this mutation on to its **progeny**.

This process of continuous genetic change has brought life from the simplest level of viruses and bacteria to the complexity of higher mammals, such as *Homo sapiens* – ourselves (see Figure 9.1, page 219).



■ **Figure 9.41** Variation in birds' beaks – all caused by mutation

EXTENSION

Explore the descent of life using online interactives: search **tree of life interactive** or try these:

www.wellcometreeoflife.org/interactive/ (requires Java or Flash)

www.onezoom.org/

http://tolweb.org/tree/

SOME REVIEW PROBLEMS TO TRY

1 A factory uses two kinds of small, low-radioactivity sources in the manufacture of smoke alarms. The factory workers are given the following health and safety instructions:

Type 1 sources

- Always wear latex rubber gloves when handling type 1 radioactive sources.
- Do not eat or drink when handling type 1 radioactive sources.

Type 2 sources

- Always wear latex rubber gloves and use tongs when handling type 2 radioactive sources.
- Do not eat or drink when handling type 2 radioactive sources.
- Always hold type 2 sources at least 10 cm away from the body.

a **State** which radioactive sources most likely correspond to type 1 and type 2.

b **Outline** the reason for each of the health and safety instructions.

2 The graph in Figure 9.42 shows the decay of a sample of the isotope carbon-14.

a Carbon-14 undergoes beta decay. **Write** a beta-decay equation for carbon-14.

b Use the graph to **find** the half-life of carbon-14 in years. **Show** on a copy of the graph how you did this.

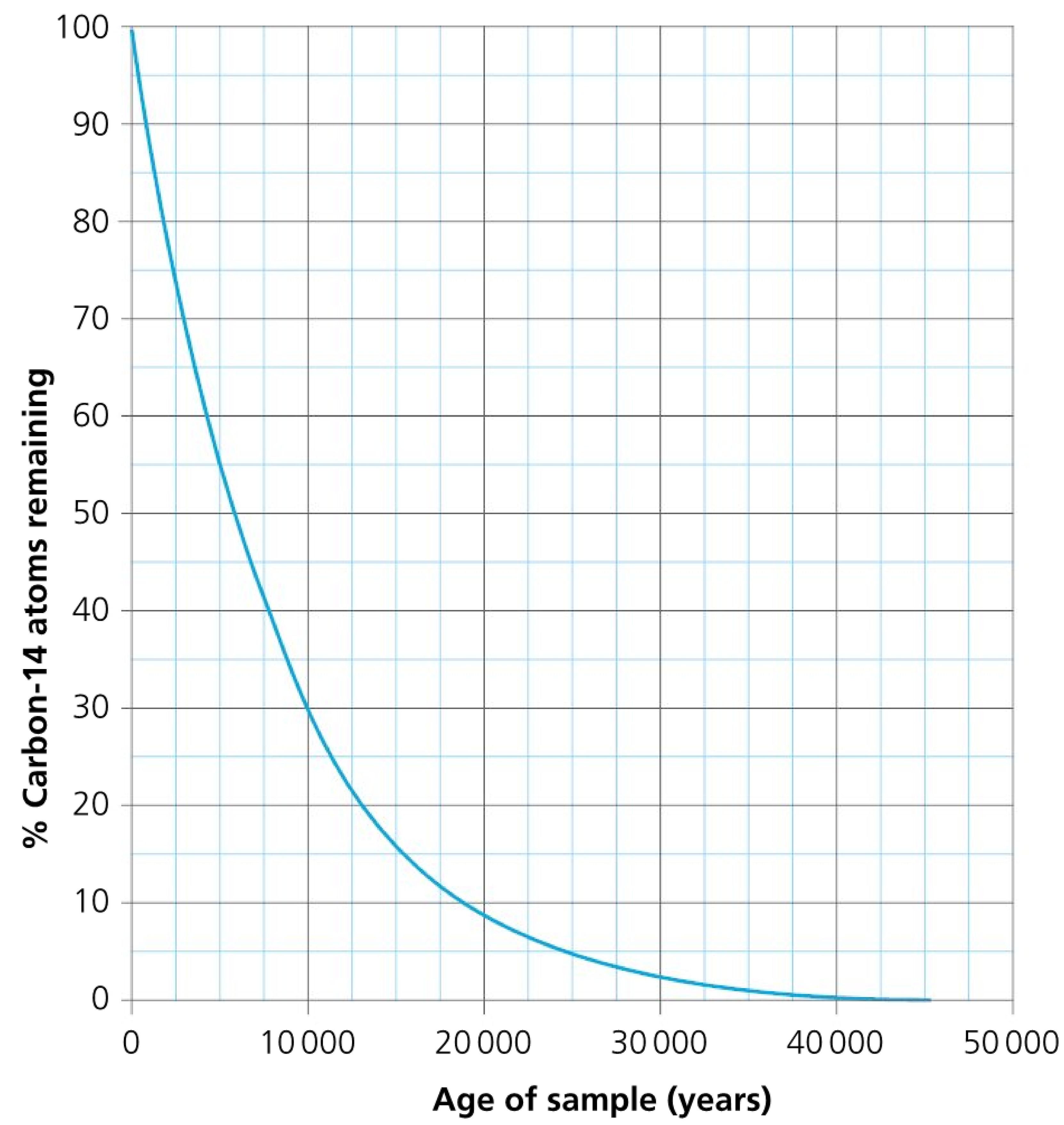


Figure 9.42 C-14 decay curve

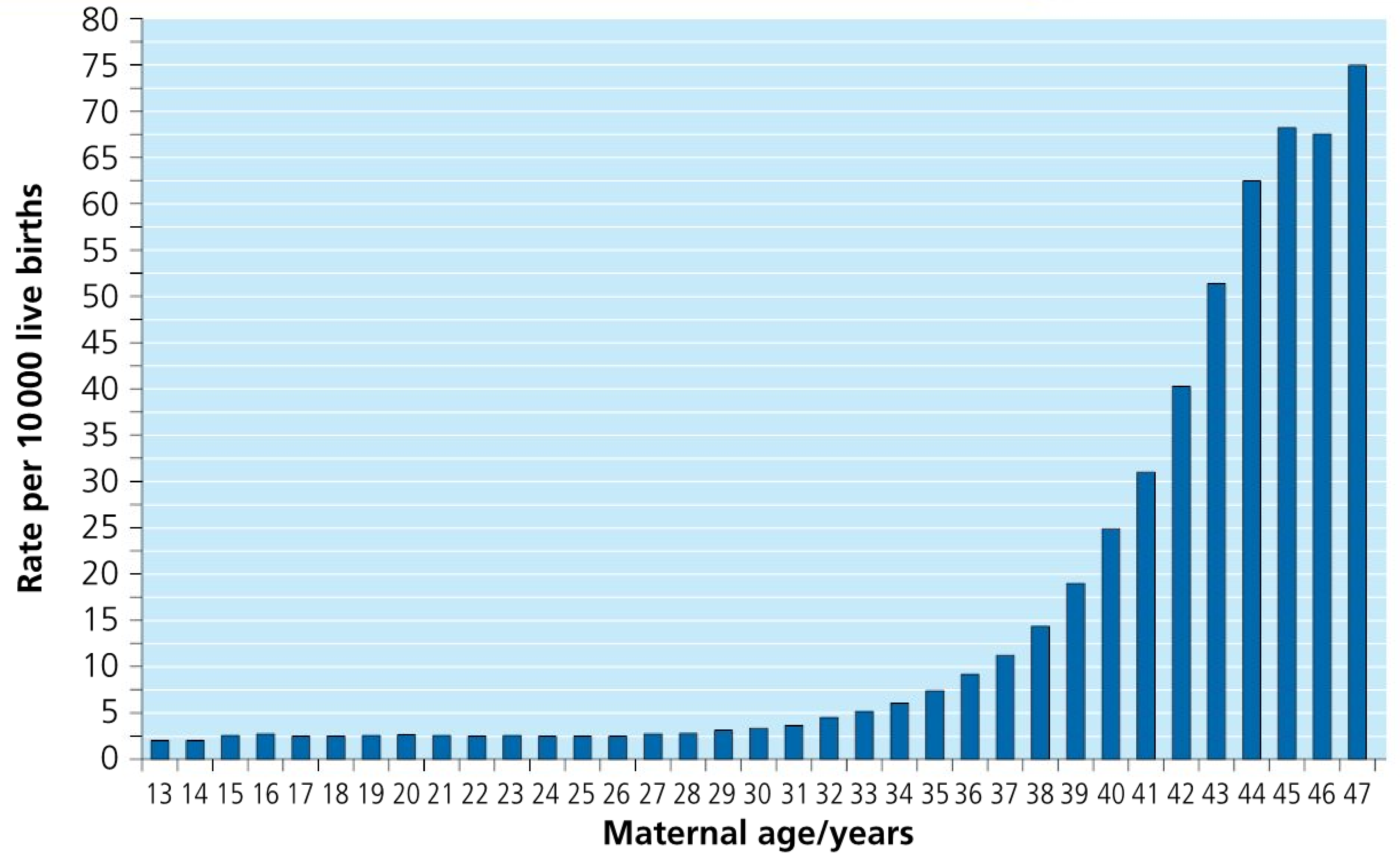
At an ancient, prehistoric burial site in the Auvergne, France, a piece of animal bone is found. Some archaeologists want to work out the age of the piece of bone. To do this, they make these measurements using two pieces of bone of the same mass:

	Count rate/counts per second
new bone	32
old bone	4

c Use this information and the graph to **estimate** the age of the piece of old animal bone.

d After taking the measurements, a physicist points out that the background radiation measurement was 1 count per second. **Calculate** the greatest uncertainty this would produce in the archaeologists' result for the age of the bone.

e Using your answers above, **suggest** why carbon-14 dating becomes less reliable the older the sample is.



■ **Figure 9.43** The risk of Down syndrome in relation to maternal age

3 Down syndrome (DS) is caused by an extra copy of chromosome 21. The World Health Organization has estimated incidence of Down syndrome between 1 in 1000 and 1 in 1100 live births worldwide. Each year approximately 3000 to 5000 children are born with this chromosome disorder. (Source: Cuckle HS, Wald NJ, Thompson SG. *Estimating a woman's risk of having a pregnancy associated with Down's syndrome using her age and serum alpha-fetoprotein level*. Br J Obstet Gynaecol. 1987; 94: 387–402)

- **a** **Explain** how an error can occur during cell division to result in such a genetic abnormality.

  Testing for DS has been made available to mothers using various medical diagnosis procedures including amniocentesis in which a small volume of amniotic fluid containing foetal cells (with DNA) is sampled for genetic abnormalities. Such procedures sometimes put the pregnancy at risk of miscarriage and are therefore only carried out with consent.

  The graph in Figure 9.43 shows the risk of DS in relation to maternal age.
- **b** **Analyse** the graph and **suggest** at what age pregnant women should be offered the test for DS.
- **c** Research to find out the risk to pregnancy from amniocentesis. Use this information to **evaluate** the factors affecting the decision whether or not to carry out the test. **Suggest** under what conditions the test might be most strongly indicated, and under what conditions it might not be advised.

Reflection

In this chapter we have looked at the complex and interlinked processes by which organisms ensure their continuity. We **defined** the genetic code and explored its universality between species. We **discussed** the opportunities that genome sequencing offered scientists to understand genomics and we **explained** how they can use this knowledge to investigate genetic disorders. We **compared** the size of genomes in organisms. We linked genetics to reproduction and **compared** different types of reproduction used by living organisms. We **applied** our knowledge of genetics to link this with cell division. We **described** the role of environment in affecting our genes and explored epigenetics. We **discussed** genetic mutations and **reflected** on their causes and impacts on our health. We **discussed** the implications of genetic modifications and **reflected** on their impact on various factors in our lives. We **described** the process by which ionizing radiations are produced by atoms and **identified** the kinds of atoms that produce them. We **identified** the most common forms of ionizing radiation, **described** their properties and **outlined** their interactions with living and non-living matter. We **evaluated** different applications of ionizing radiation and we **discussed** the beneficial and malign effects of ionizing radiation on living things.

Use this table to reflect on your own learning in this chapter					
Questions we asked	Answers we found	Any further questions now?			
Factual					
Conceptual					
Debatable					
Approaches to learning you used in this chapter:	Description – what new skills did you learn?	How well did you master the skills?			
		Novice	Learner	Practitioner	Expert
Learner profile attribute(s)	Reflect on the importance of being reflective for your learning in this chapter				
Reflective					

10 What is our place in the Universe?

We understand how we **fit in the Universe** through **interaction** with **systems** on Earth and in space.

CONSIDER THESE QUESTIONS:

Factual: What is in the Universe? What methods do scientists use to gather information about the Earth's place in the Universe? How does electromagnetic radiation interact with matter? What are the systems that make the Earth work?

Conceptual: How do the Earth's systems interact with each other and with surrounding space? How do we make use of the Earth's natural resources?

Debatable: How have cosmological models changed our perspective?

Now **share and compare** your thoughts and ideas with your partner or with the whole class.

IN THIS CHAPTER, WE WILL …

- **Find out** how our perspective of our place in the Universe has changed as we have devised new ways to gather information, how the Earth and its neighbourhood came into existence and how we fit into the Earth's systems.
- **Explore** how humanity has learnt to extract and exploit natural resources and how we have used our scientific knowledge to understand the impact of our action.
- **Take action** to raise awareness of environmental change through the use of images of Earth taken from space.

These Approaches to Learning (ATL) skills will be useful …

- Communication skills
- Collaboration skills
- Critical-thinking skills
- Information literacy skills
- Creative-thinking skills
- Transfer skills
- Organization skills

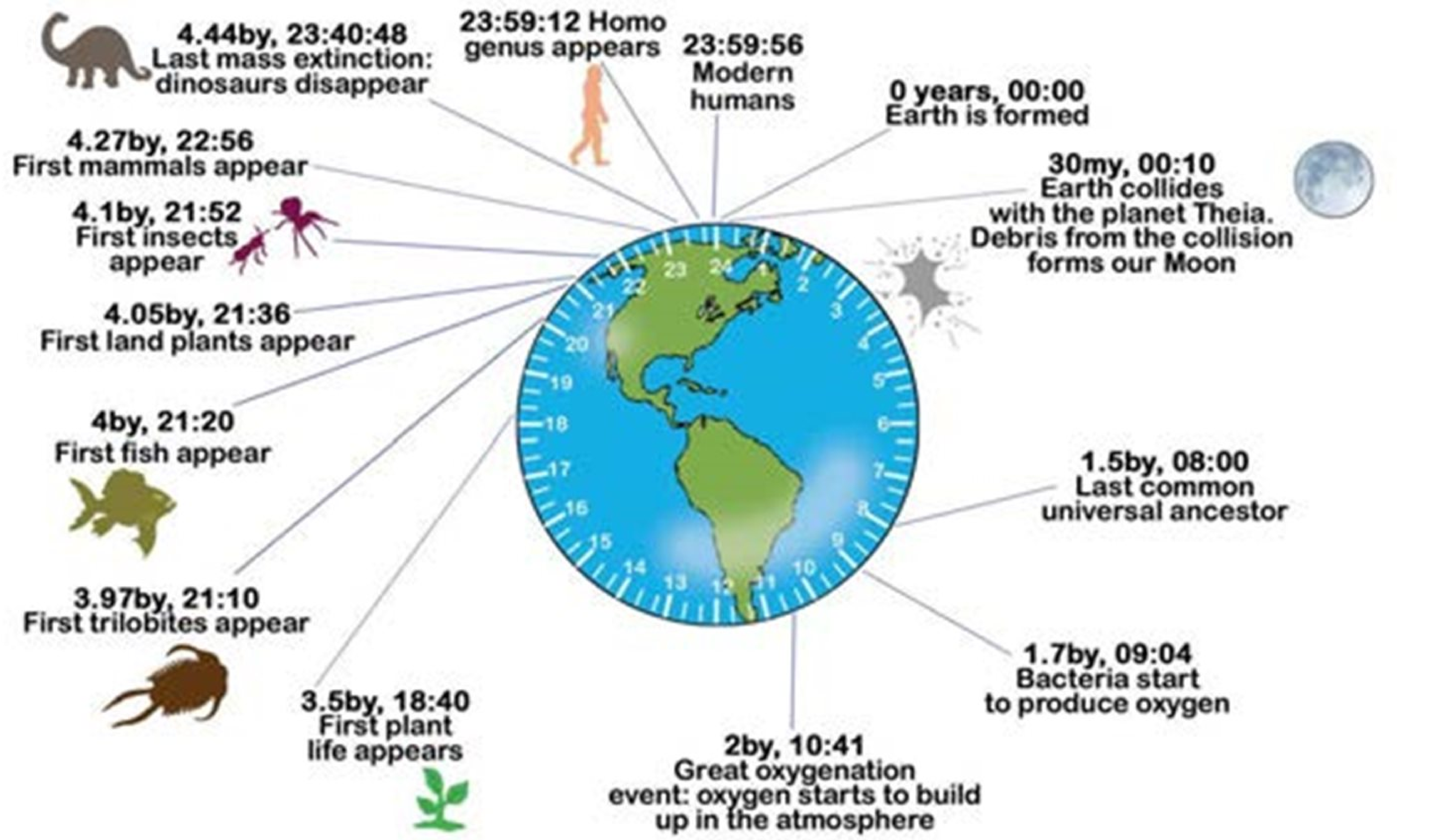


Figure 10.1 Earth history in 24 hours

Assessment opportunities in this chapter:

The activities in this chapter will help you develop and evaluate your learning in these MYP Sciences learning objectives:

- **Criterion A:** Knowing and understanding
- **Criterion B:** Inquiring and designing
- **Criterion C:** Processing and evaluating
- **Criterion D:** Reflecting on the impacts of science.

KEY WORDS

dissolve	planet
exploit	ray
extract	satellite
instrument	system

We will reflect on this learner profile attribute …

- Caring – we will reflect on the impact of our activity on the Earth's systems and consider what can be done to avoid negative consequences.

SEE–THINK–WONDER

Look at Figure 10.1. You may also like to search: **video history Earth 24 hours** and watch a video or animation on a similar theme. What do you **see**? What does this make you **think** about the Earth and its history? What does this make you **wonder** about the Earth and our place on it?

When we consider how much of the Earth's history we have inhabited – or, to put it another way, how long the Earth was doing just fine without us – then the impact of our actions becomes really apparent, as should the responsibility we carry for those actions.

In this chapter we will look at the way that the systems of the Earth relate and interact with each other and with the space around us. We will consider how we extract what we need from our planet and what this activity implies for us and for our only home: the Earth.

What is in the Universe?

WHAT IS OUT THERE?

You may recall that in *MYP Sciences by Concept 1:* Chapter 6 we explored the different objects that can be found in space, including human-made artefacts such as the International Space Station. Figure 10.2 shows some of the other objects. All of these can be seen with the naked human eye, provided the night is dark and clear enough, although to see them in detail requires the use of a **telescope**.

The following activity can be used to refresh your memory and extend your understanding of these objects.

ACTIVITY: Modelling the Universe

ATL

- Information literacy skills: Understand and use technology systems

For this activity you will need access to a tablet computer or a smartphone.

Use the device to download a night sky observatory app such as Night Sky (iOS and Android), Google Sky Map (Android) or Star Walk 2 (iOS and Android).

In pairs or groups, point the smartphone or tablet at the sky (you will probably need to enable GPS for this). Look around the sky and see if you can **identify** the locations of:

- **a planet in the Solar System**
- **the Moon**
- **a galaxy**
- **a nebula.**

Now download an image of an example of each of the objects. Research some information on them using these guiding questions:

- **What is it made from?**
- **How large is it?**
- **How distant is it from the Earth?**

Organize this information on one side of a sheet of paper. In the classroom, or a long a corridor, position your information sheets from nearest to most distant.

Now **calculate** the scaled distance of the object using a scale of 1 mm = 100 000 km (so a scale of 1 : 100 000 000 000 or 1 : 10^{11}).

Calculate how far apart the information sheets would have to be to represent the scaled distance of the objects from Earth accurately.

Figure 10.2 (a) M42 ('Orion') nebula; (b) M31 Andromeda Galaxy; (c) M45 the Pleiades star cluster

THE LIFE OF A STAR

When people have looked at the night skies through history, they have often assumed that the stars and other objects have been that way forever. However, the last 200 years of scientific research have taught us that the night sky has changed over the course of human history and sometimes the changes can be quite rapid. In a Chinese book called *Ch'ien-han-shu*, which records astrological events back to the year 5 BCE, historians have found this reference:

> 'In the second year of the period of Ch'ien-p'ing, second month, a hui-hsing appeared in Ch'ien-niu for more than 70 days.'

Similarly in the Korean chronicles *History of the Three Kingdoms – The Chronicle of Silla (Samguk Sagi)*, a reference is found to:

> 'Year 54 of Hyokkose Wang, second month Chi-yu, apo-hsing appeared in Ho-Ku.'

The Chinese and Korean astrologers recorded a bright 'guest star', dating in modern calendar terms to July 1054, in a place where we now see M1, the Crab Nebula. Then again, in 1572 Tycho Brahe made brightness measurements of a star which suddenly lit up the whole sky at night, then disappeared after a few days.

When we make observations of the Universe around us, we see stars of many different kinds to our own Sun. Astronomers have discovered that stars do indeed change quite dramatically during their 'lifetime'.

The time taken for stars to complete the life cycle depends on their mass, but it is always tens of billions of years. Fortunately for us, our Sun is a fairly average 'main sequence' star in the middle of its life, about 4.6 billion years through its likely lifetime of 10 billion years. The Sun is a huge sphere consisting mostly of hydrogen gas. The core of the Sun is dense enough for nuclear fusion to take place, in which individual nuclei are forced together to make the nuclei of heavier elements. Since larger nuclei require less energy to bind them together, nuclear fusion releases some of this energy as radiation. This radiation causes a temperature at the Sun's core thought to be around 15 million degrees Kelvin, although at the surface the gas cools to a mere 5700 Kelvin. At the moment, most of the heat generated in the Sun comes from fusion of hydrogen to helium, although evidence shows us that heavier elements are also being made inside the Sun.

Figure 10.3 Crab nebula supernova remnant

We now realize that the heavier elements we find in nature – in fact, everything with an atomic number greater than that of iron – must have been made inside heavy stars whose gravitational attraction provides sufficient energy for **nucleosynthesis** of these elements to occur. Such elements are released into the Universe when the star turns nova, and we find some of them in our own bodies. We truly are made from star material.

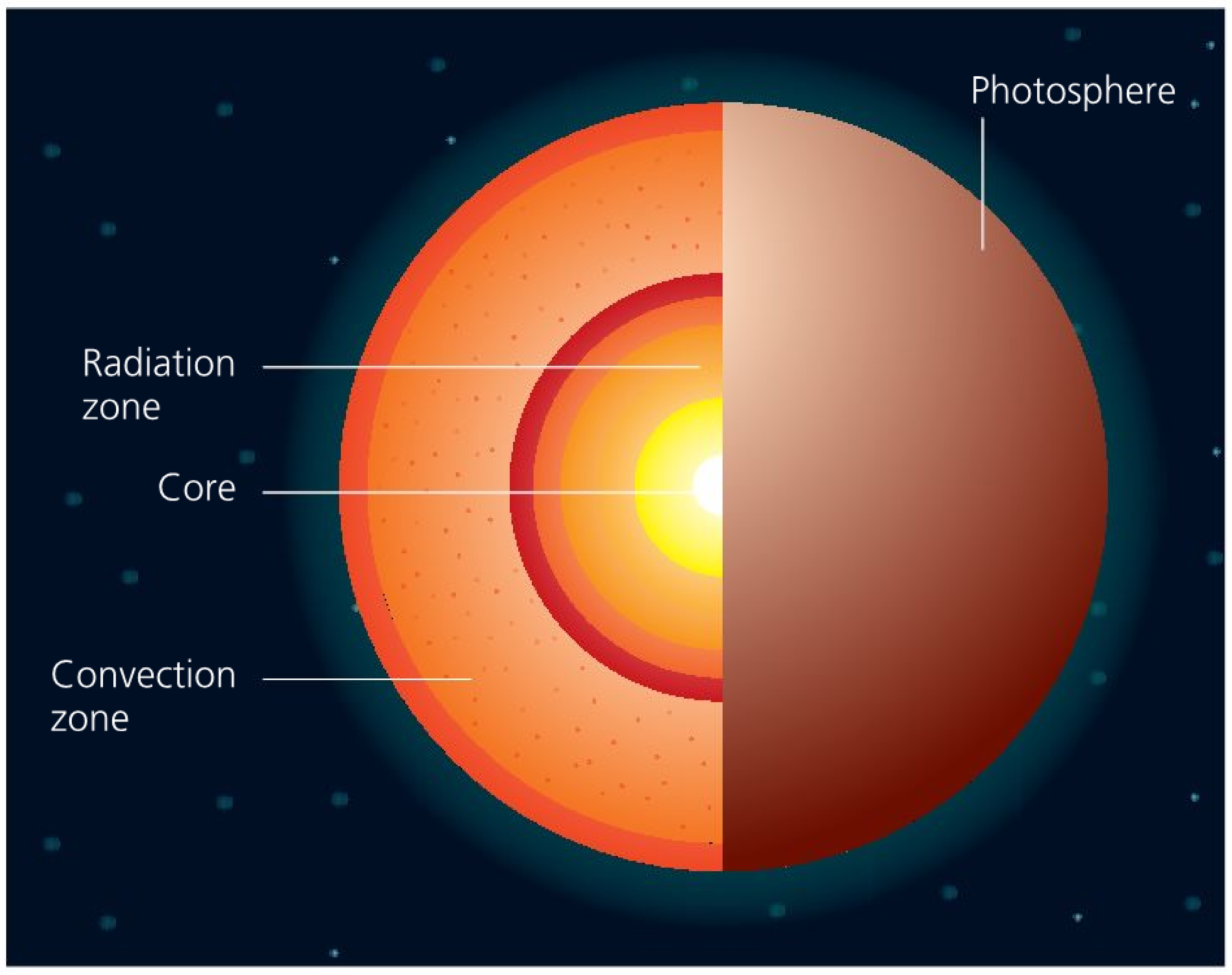


Figure 10.4 Cross-section through the Sun

ACTIVITY: It's a star's life

ATL

- Information literacy skills: Access information to be informed and inform others
- Critical-thinking skills: Gather and organize relevant information to formulate an argument

Search **life cycle star** to research the life cycle of stars using online videos.

Match the labels and descriptions from Table 10.1 to the parts of the schematic diagram (Figure 10.5).

Interpret the information you have collated in the diagram to **deduce** the variable that determines whether a star will form a black dwarf or a black hole.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

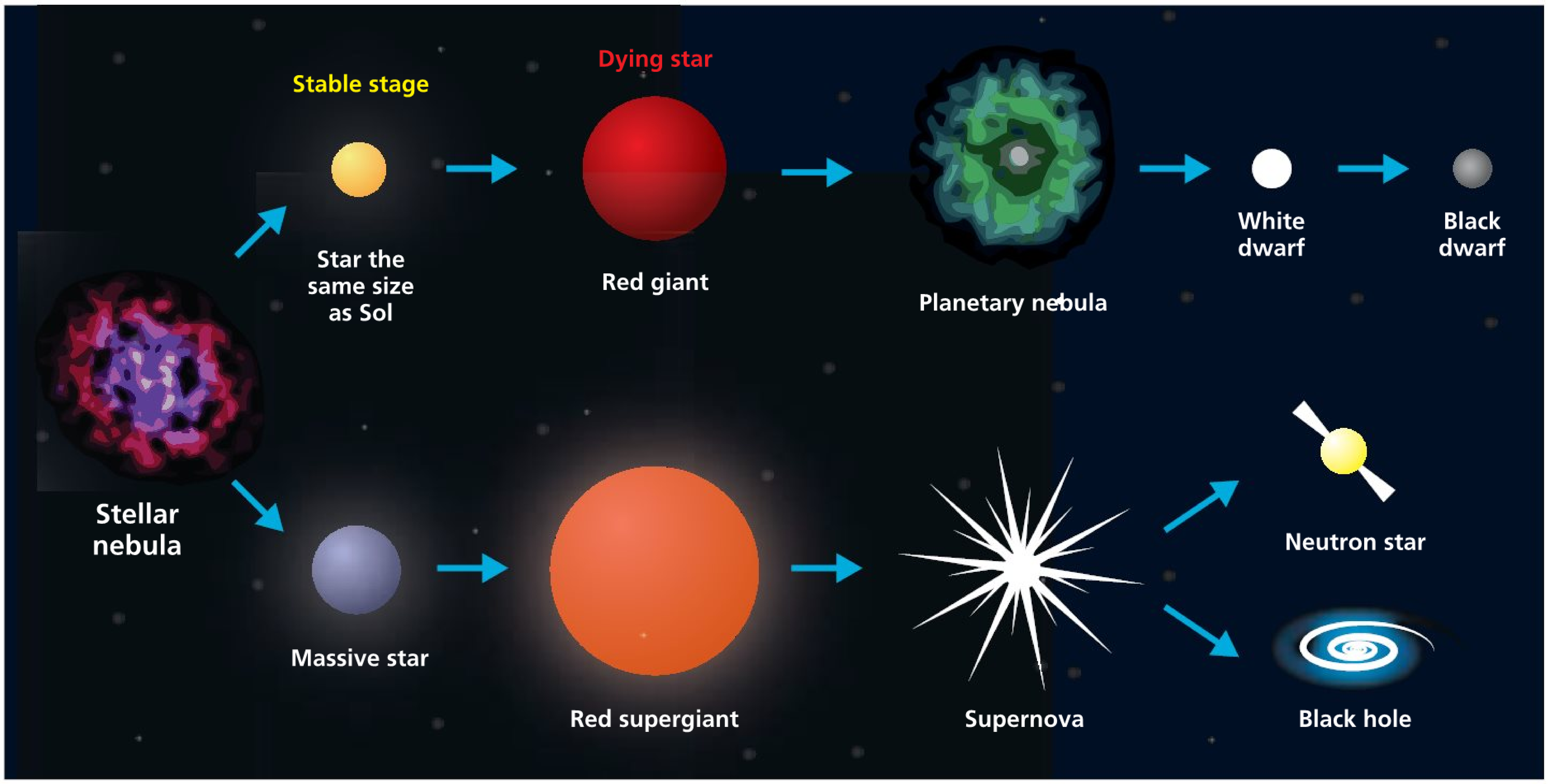


Figure 10.5 The life cycle of a star

Description
large red star formed when a massive star begins to fuse heavy elements in its core
very massive object whose gravitational pull prevents even light from escaping
small, bright star that is fusing heavy elements very rapidly
large cloud of gas and dust slowly collapsing under gravitation
very dense remnant of a supernova where individual nucleons have fused under gravitation to form neutrons
very large stars that are rapidly fusing hydrogen to helium and heavier elements still
star around the same size as the Sun that is mostly fusing hydrogen to form helium
gaseous remains of outer layers of a main sequence star blown into space
'dead' remnant of a white dwarf made mostly from iron
exploding core of a massive star after supergiant collapses inward; very bright for a short time
large red star formed when a main sequence star begins to fuse heavy elements in its core

Table 10.1

What methods do scientists use to gather information about the Earth's place in the Universe?

Just as for the tiny scales of atoms, it can be difficult for us to visualize the huge scales of space. Astrophysicists have defined some different 'rulers' to make the scale of things easier to manage. Within the Solar System, one such ruler is the **astronomical unit**:

1 astronomical unit (AU) = mean distance from centre of Earth to centre of Sun = 149.6 million km

When making observations across the vast distances of deep space, we have to factor in a new variable. The speed of light in a vacuum, c, has a constant value of around $3 \times 10^8\,\mathrm{m\,s^{-1}}$. The fact that light does not travel at infinite speed and so does not arrive instantaneously has a significant implication. In most circumstances on Earth, the speed of light is so great that the time for light to travel from source to observer is not significant, but when we are looking at distant objects, this time lag makes a difference. The light from our own Sun, for example, takes around 8 minutes to travel to the Earth. The light from the next nearest stars takes approximately 4 years to reach us. This means that when we observe the Sun, we are seeing it as it was 8 minutes ago and we observe the next nearest stars as they were 4 years previously!

For deep-space measurements, astrophysicists define another unit as a ruler for distance, called the **light year**. A light year is *not* a unit of time, but of distance, since

1 light year = distance travelled by light in one year = ct

So 1 light year = 3×10^8 metres per second $\times$ 31 557 600 seconds

$$1\,\mathrm{ly} = 9.4607 \times 10^{15}\,\mathrm{m}$$

In *MYP Sciences by Concept 2:* Chapter 4 we explored the way in which light allows us to see objects and how we can manipulate light to change what we see. Before continuing, check your understanding of this material with the following activities.

ACTIVITY: Making images

ATL

- Critical-thinking skills: Practice observing carefully in order to recognize problems

Aim: To observe the effect of biconvex and biconcave lenses

Equipment: You will need a biconvex lens, a biconcave lens, a bright source of light and a piece of squared paper.

Experiment 1

Hold the biconvex lens up to a bright source of light that is a fairly large distance away, for example on the other side of the room (a window or a light bulb).

Hold a piece of squared white paper behind the lens and move it steadily away from you and towards you until you see an image produced on it.

Describe the image you see with some of these words:

diminished	inverted	magnified	upright

This image is being projected into an actual, real position in space; this is why we can see it on the screen. For this reason it is called a real image.

Now try the same with the biconcave lens. Describe what you see on the paper.

Experiment 2

Take the biconvex lens and hold it close over this page. Look *through* the lens. Move the lens back and to until you see a clear image.

Describe what you see in the lens, using the correct terms from the box.

This image cannot be projected onto a screen, because it does not exist as such in real space; it is being produced by the rays that pass through the lens and into your eye. This is called a virtual image.

Now try the same with the biconcave lens. **Describe** what you see this time.

ACTIVITY: Reviewing viewing

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument

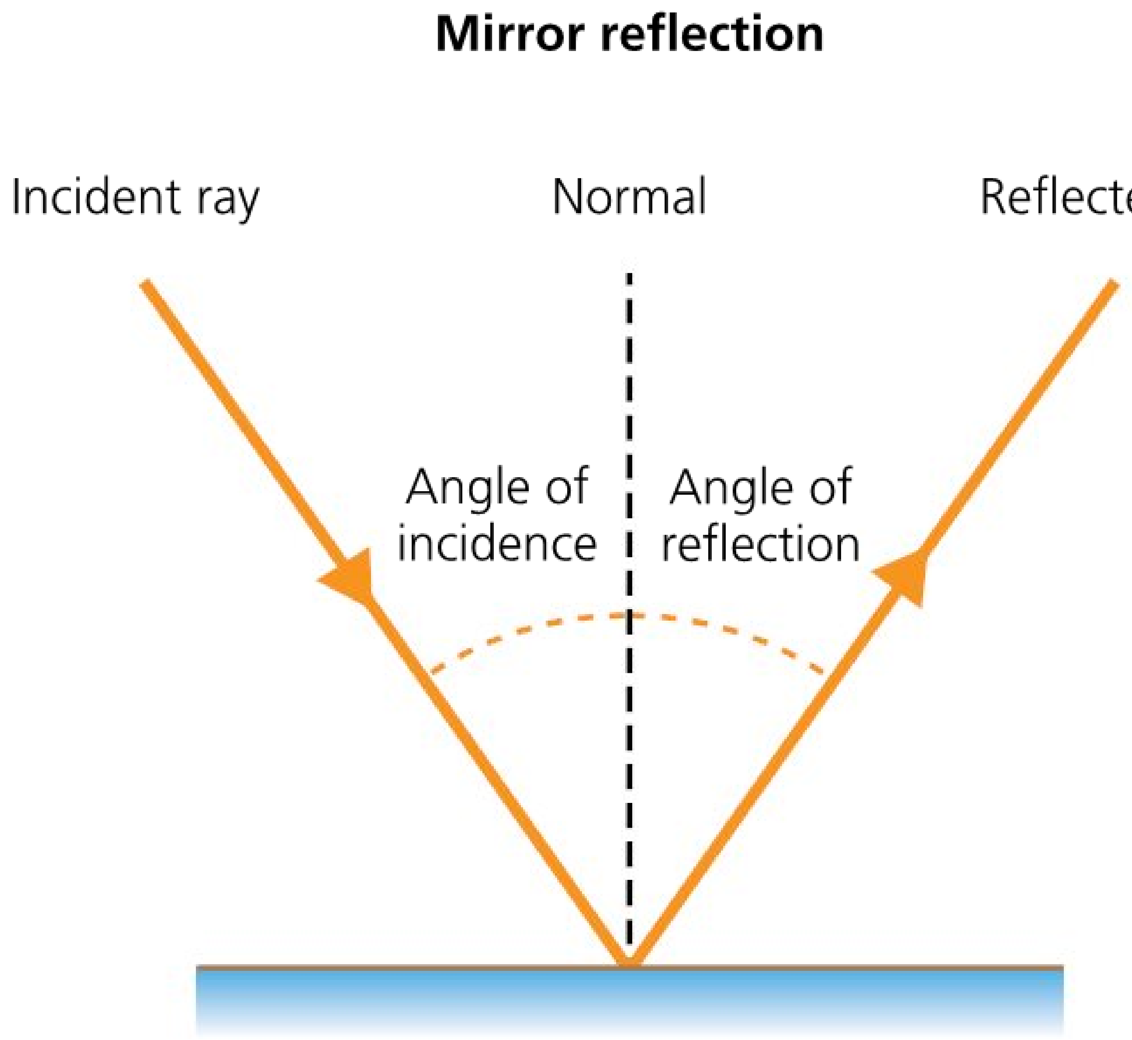


Figure 10.6 Reflection in a mirror

Look at Figures 10.6 and 10.7 and review the scientific terms in the box below.

reflect	ray	focal point	convex
incident	scatter	converge	concave
parallel	refract	diverge	

With reference to the diagrams, **apply** the scientific terms correctly in order to **explain** the following:

- **how a mirror reflects the image of our face back towards us**
- **how any lens affects light rays that fall onto its surface**

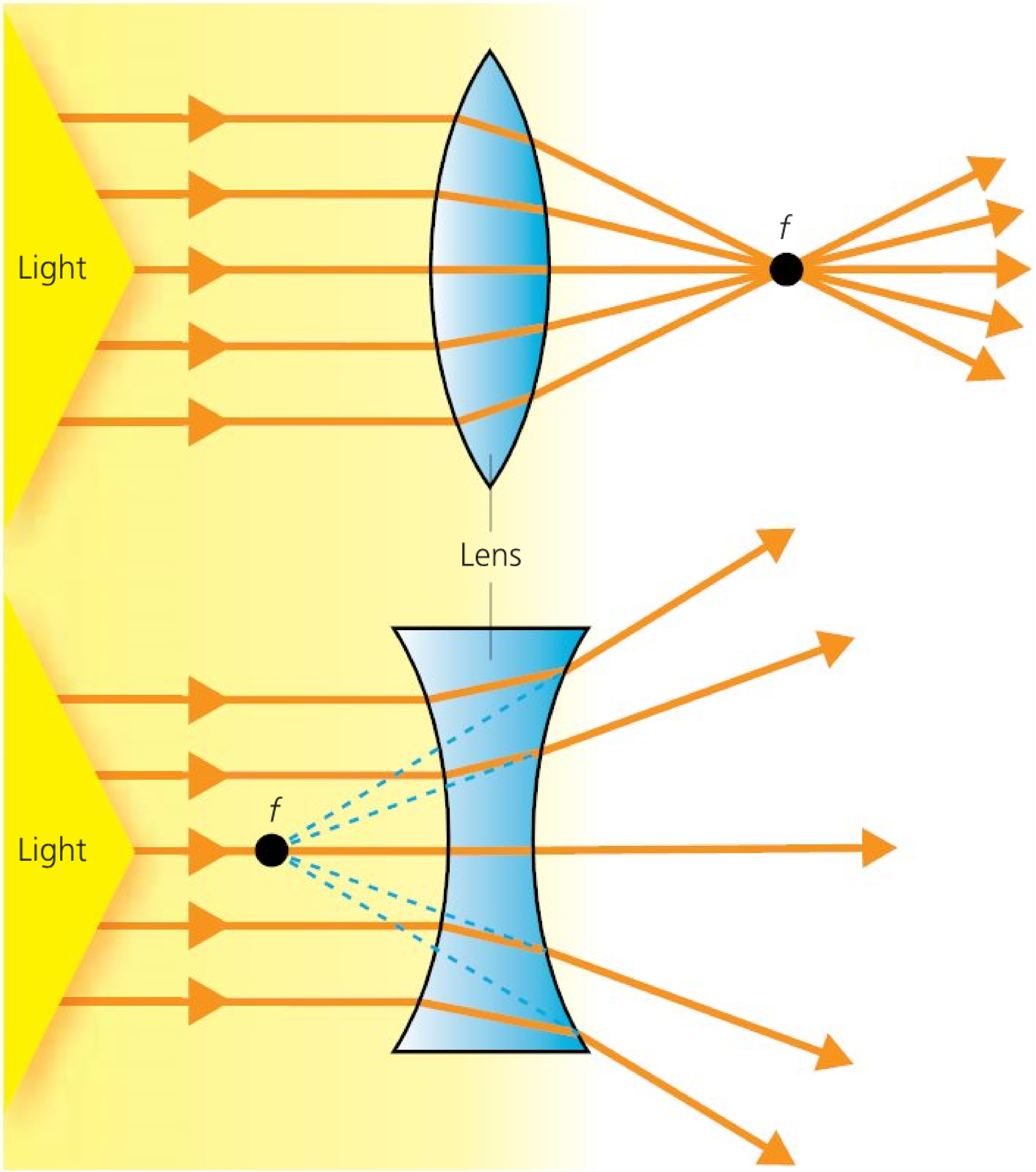


Figure 10.7 Biconvex and biconcave lenses

- **how a lens can be used to bring parallel light rays together at a point**
- **how a lens can be used to cause parallel light rays to spread apart.**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

ACTIVITY: The longest ruler

ATL

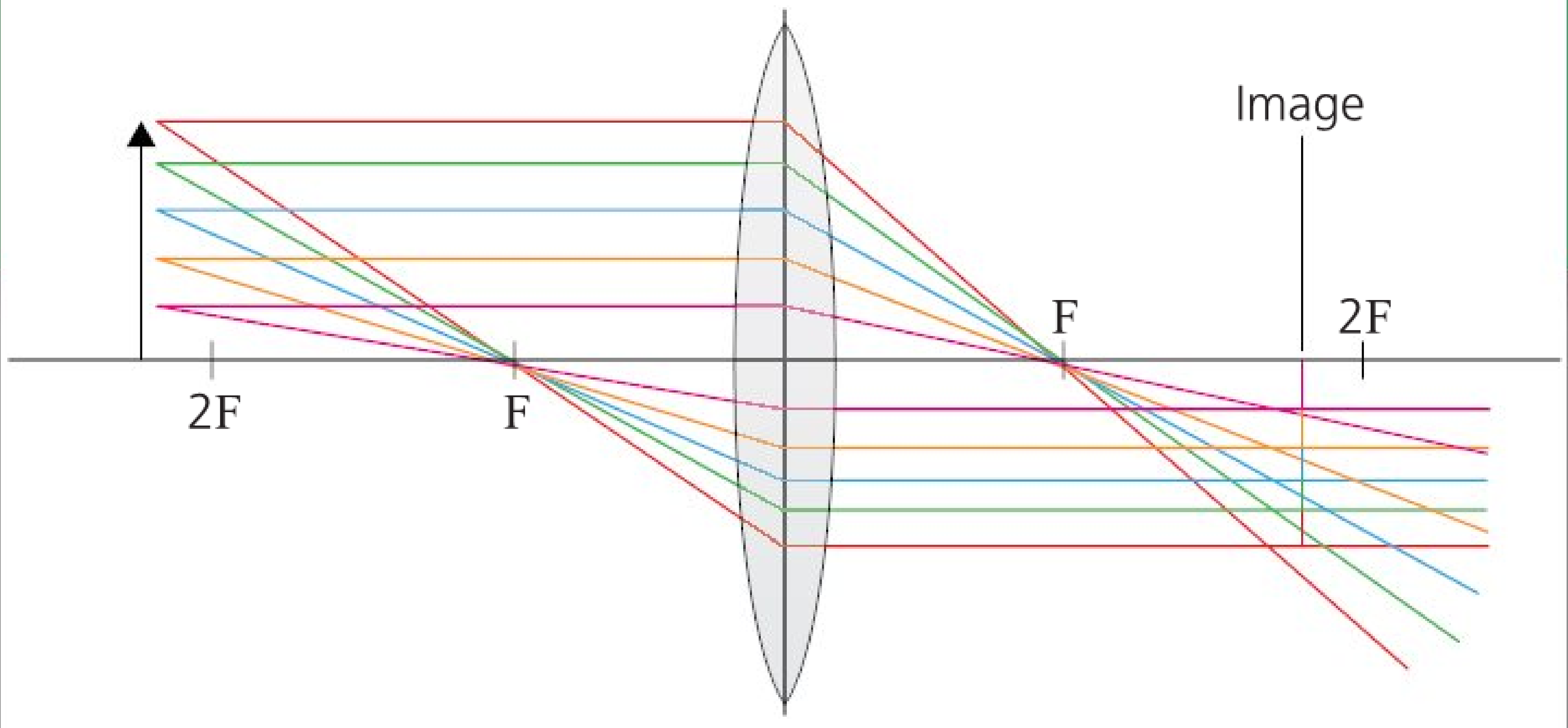
- Information literacy skills: Access information to be informed

In order to gain some sense of astronomical distance, we can use the light year to gauge the distances in the observable Universe.

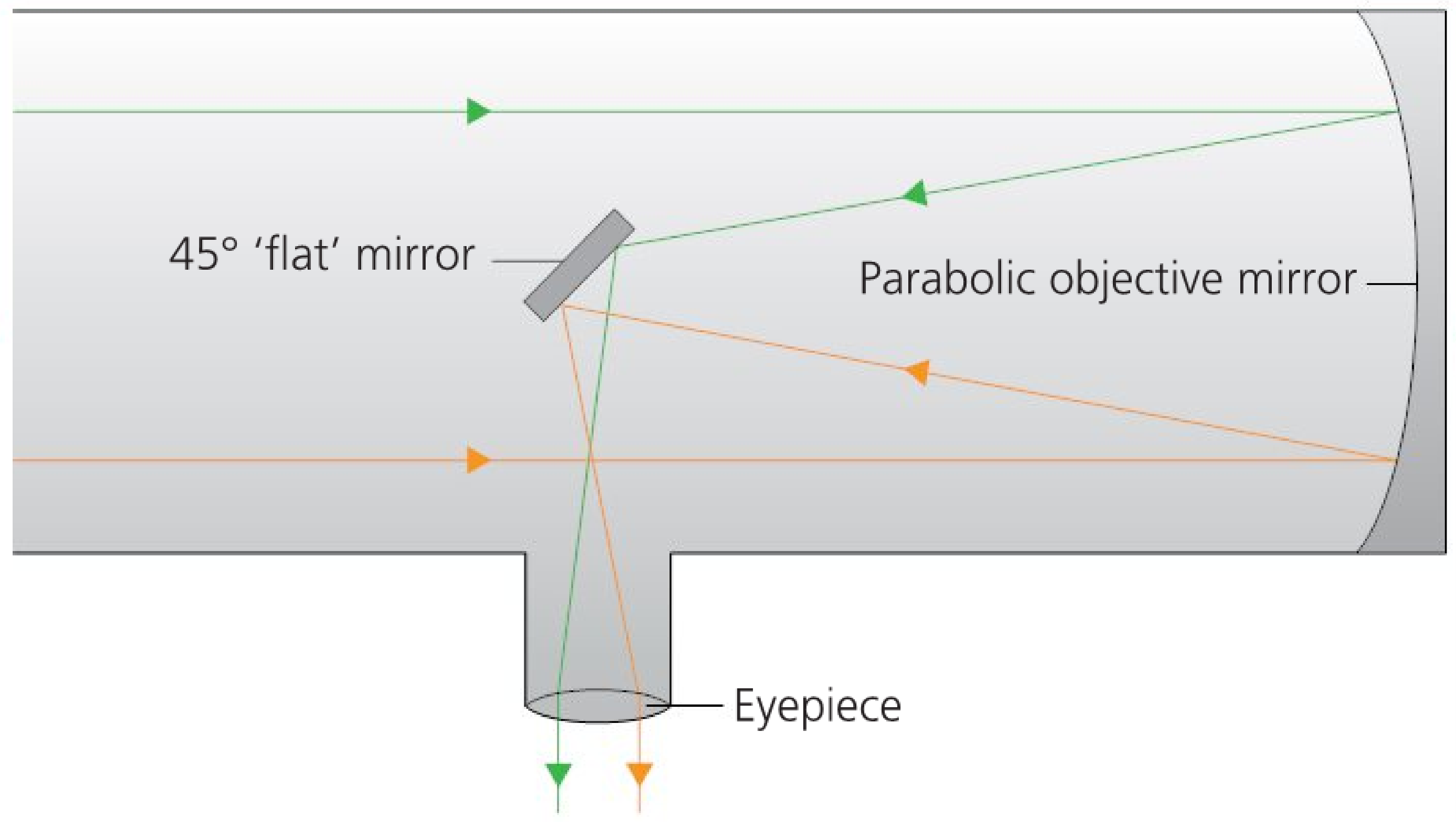
Search **distance light years** followed by the names of the following objects to find their distances.

Object	Distance (ly)
planet Neptune	
star Proxima Centauri	
centre of our galaxy	
pulsar CP1919	
Andromeda Galaxy M31	
Hubble telescope deep space view objects	

Table 10.2



■ **Figure 10.8** Ray diagram – biconvex real image formation



■ **Figure 10.9** Newtonian reflecting telescope

Ray diagrams are useful schematic simplifications because they allow us to model the behaviour of light passing through the lens and they give us information about the kind of image that will be produced.

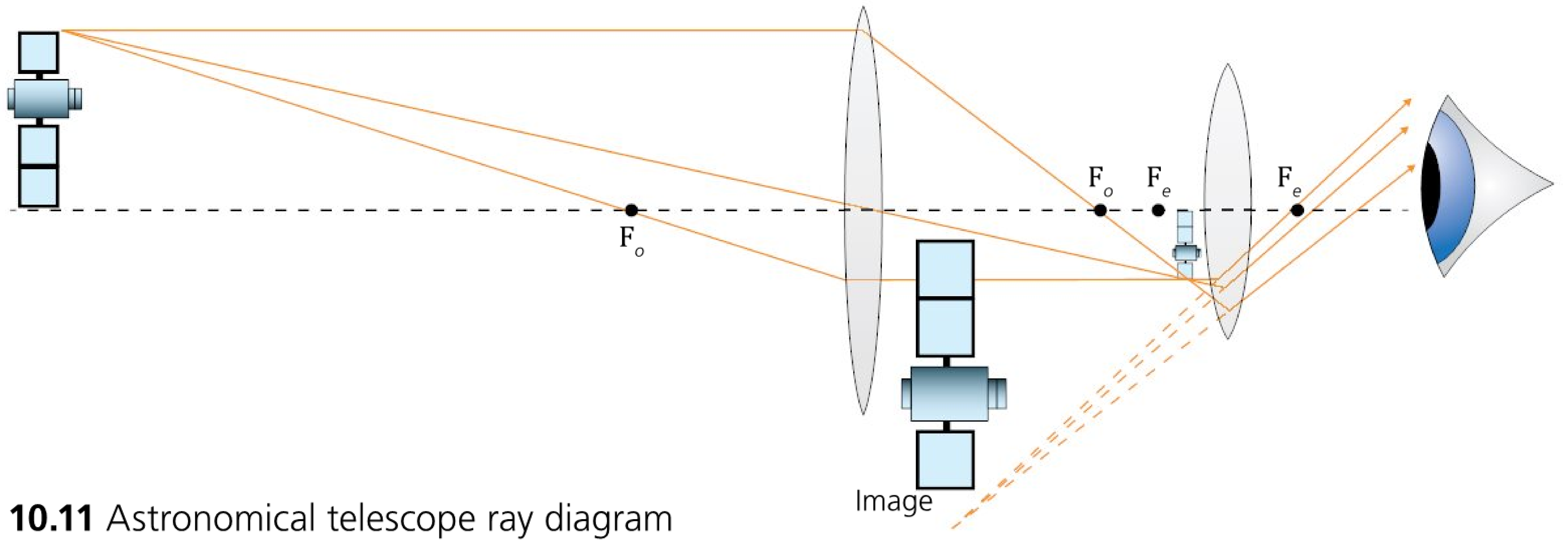
In Figure 10.8, we can see that the rays that come from the top of the object are all reassembled on the other side of the lens at the same point, relative to the lens. This forms a real image as we saw in the Activity *Reviewing viewing*.

A telescope uses lenses or mirrors to produce magnified images of distant objects. Some of the first astronomical observations made using a telescope were recorded by Galileo Galilei in a book called *The Starry Messenger* in 1610. Although he didn't invent the telescope, Galileo built his own version using two biconvex lenses together. In a telescope, the first lens, or objective lens, is used to gather the light from a distant object and so it forms a real image inside the telescope tube. This image then forms the object for the second, or **eyepiece**, lens. The eyepiece is adjusted so that the real image is close to the lens and so it magnifies the real image again, forming a much-magnified virtual image in the eye of the observer. It is thought that Galileo's telescope achieved a magnification around 3, although even small modern telescopes achieve much bigger magnifications than this!

Another way to produce a large magnification is to use a curved mirror as the objective. A concave mirror has the effect of focusing light rays in the same way as a convex lens. Isaac Newton developed a telescope that used a concave mirror to produce a real image that was then magnified by an eyepiece lens in the same way as the astronomical refracting telescope.

Most astronomical telescopes, although not all, are now reflector telescopes of different types. They produce extremely high magnifications and **resolutions**.

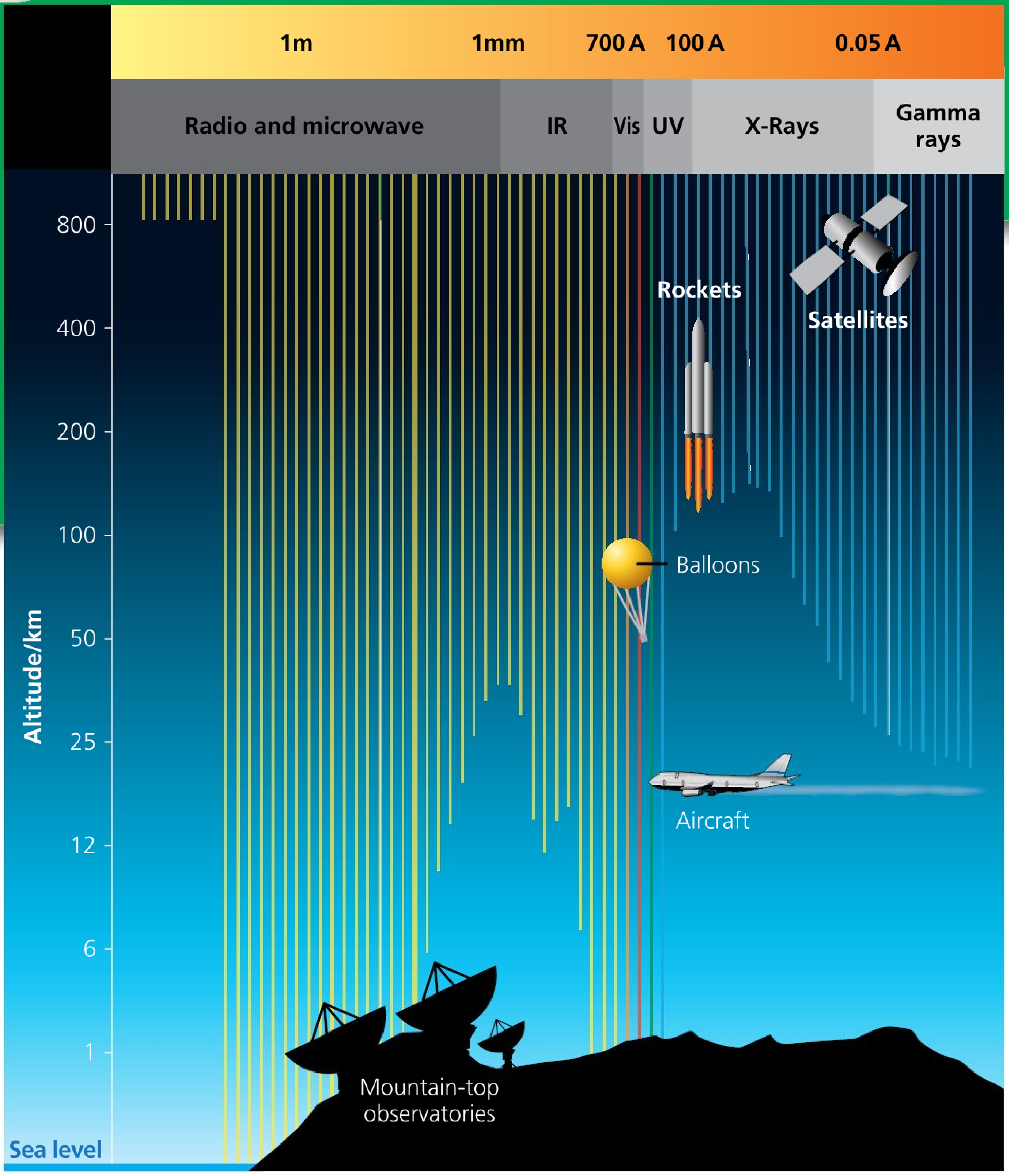
■ **Figure 10.10** The Keck telescopes at Mauna Kea Observatory, Hawaii, use 10 m diameter mirrors with 17.5 m focal lengths



■ **Figure 10.11** Astronomical telescope ray diagram

EXTENSION

Since its launch, the Hubble has produced astonishing images of deep-space objects. Use NASA's dedicated site http://hubblesite.org/ to explore the Universe through the eye of Hubble.



■ **Figure 10.12** Radiation penetration of atmosphere

Astronomical observatories are generally situated on mountain tops, high above sea level. The atmosphere acts as a very effective radiation filter. While this filter is very good for life on the Earth's surface, it is not so good for astronomers who want to gather as much information as they can from the radiation arriving at the Earth.

The highest telescopes are not on Earth at all, but in orbit around Earth. The Hubble space telescope is one such astronomy platform launched in 1990, carrying a 2.4 m diameter optical reflecting telescope.

But seeing is only part of the story. While optical telescopes give us valuable information, the Universe is alive with radiation from right across the electromagnetic spectrum. Astronomers use telescopes that are designed to detect radiation from the radio region right through to the gamma-ray regions of the spectrum, allowing us to 'see' the Universe through very different eyes, each revealing different information to us.

■ **Figure 10.13** Hubble space telescope

How does electromagnetic radiation interact with matter?

The work of the British physicist James Clerk Maxwell (1831–79) in electricity and magnetism enabled physicists to understand light as an electric field and a magnetic field oscillating in space. The field strength is changing at right angles to the direction of propagation of the wave, so we regard light as a **transverse** wave (see *MYP Sciences by Concept 2:* Chapter 4 to refresh your memory about wave types!)

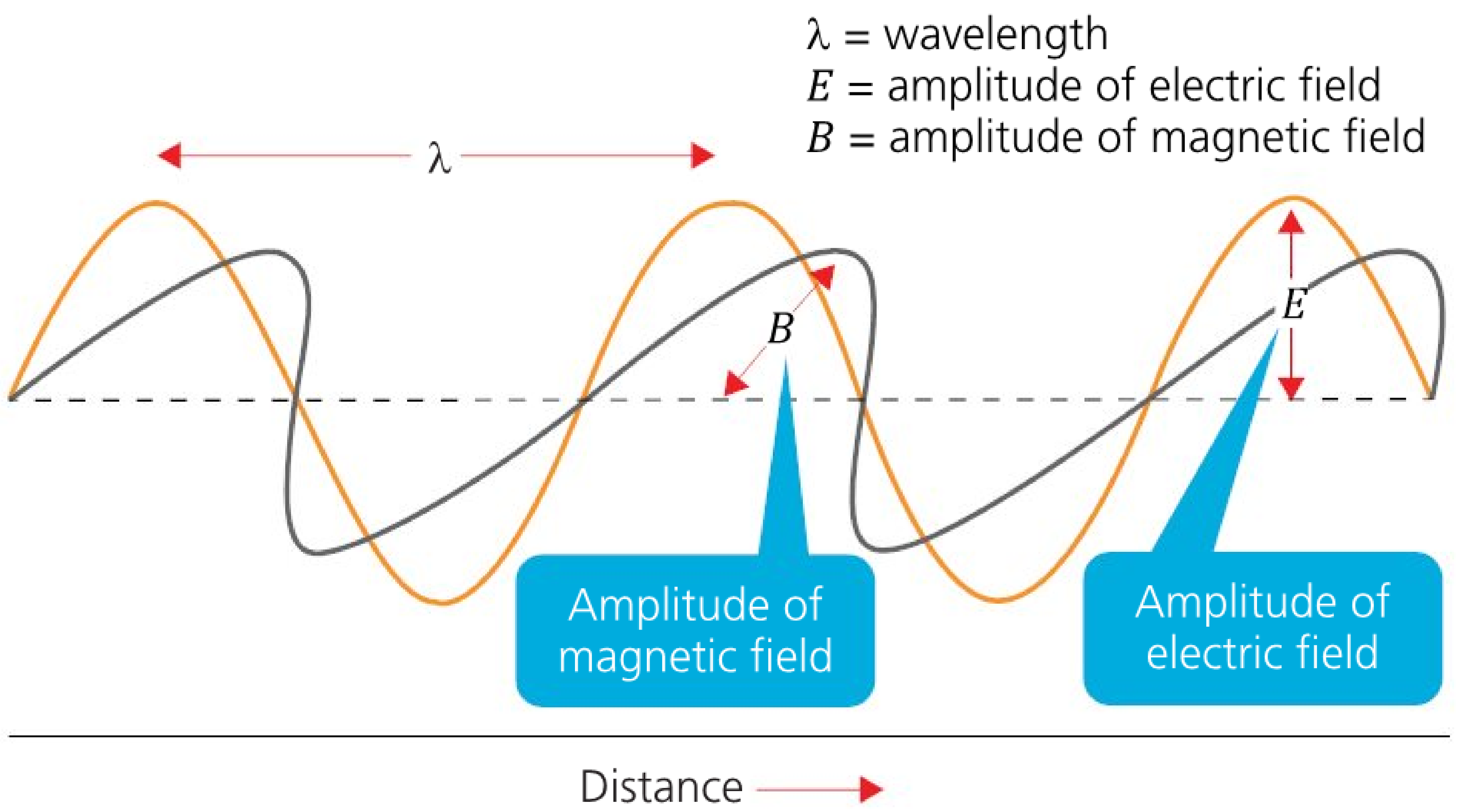


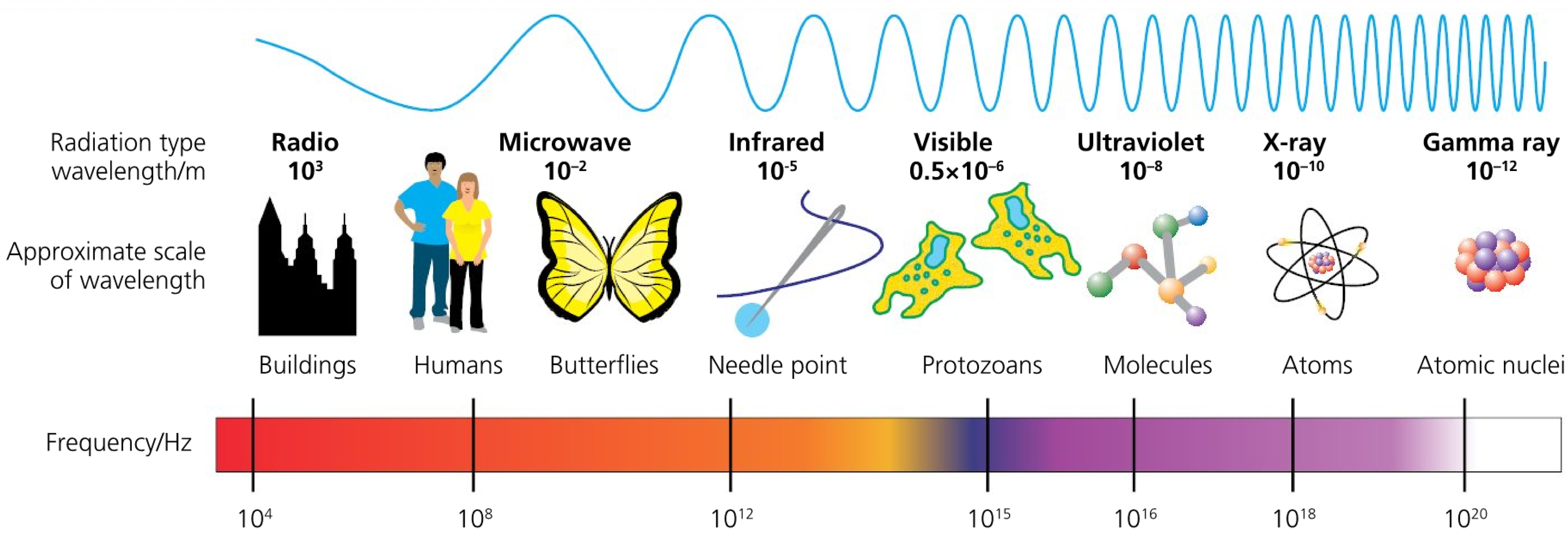
Figure 10.14 Light is a transverse oscillation of electric and magnetic fields at right angles to each other

Of course we experience light with our eyes. The **intensity** of a wave is related to the square of its amplitude. We experience changes in the frequency of light as colour, at least for those frequencies that are visible to us. However, it was soon clear to physicists that many other kinds of energy were transferred as oscillating electromagnetic (EM) fields. In Chapter 5 we encountered the phenomenon of heat radiation. Heat can transfer through a vacuum in the form of **infrared** radiation, which we do not 'see', but which we experience as a heating effect in matter such as our skin.

Other creatures are capable of experiencing still other frequencies of EM radiation. Pollinating insects can often 'see' high-frequency ultraviolet radiation, since this enables them to identify flowers that reflect these radiations very strongly. Similarly, rattlesnakes can 'sense' the infrared radiation produced by their prey.

Physicists have classified the kinds of EM radiation in terms of their frequency and their effect on matter. This classification is then represented as the electromagnetic (EM) spectrum.

In *MYP Sciences by Concept 2:* Chapter 4 we saw how colours can be produced through adding or subtracting different frequencies of visible light. As the EM spectrum shows us, EM radiation of different frequencies has different effects on matter it encounters.



■ **Figure 10.15** The electromagnetic spectrum

ACTIVITY: Seeing colours

ATL

- Critical-thinking skills: Draw reasonable conclusions and generalizations

Aim: To measure the bandwidth of coloured filters

Background

A coloured filter is used to absorb selected wavelengths from incident light and transmit the remainder. This reduces the range of wavelengths in the transmitted light and this range of wavelengths is called the **bandwidth**.

A prism or a diffraction grating can both be used to separate out the different wavelengths in the incident light spatially to make a **spectrum**.

Variables

Independent: colour of filters – red, yellow, green, blue, violet
Dependent: bandwidth of transmitted light
Controlled: intensity, wavelength composition of incident light

Procedure

Set up the apparatus as shown in the diagram. The diffraction grating or the prism can be placed at point 'X'.

You will need to adjust the angle of incidence of the initial light ray carefully to find the transmitted beam on the screen. **Do not** change the distance of the prism/diffraction grating to the screen.

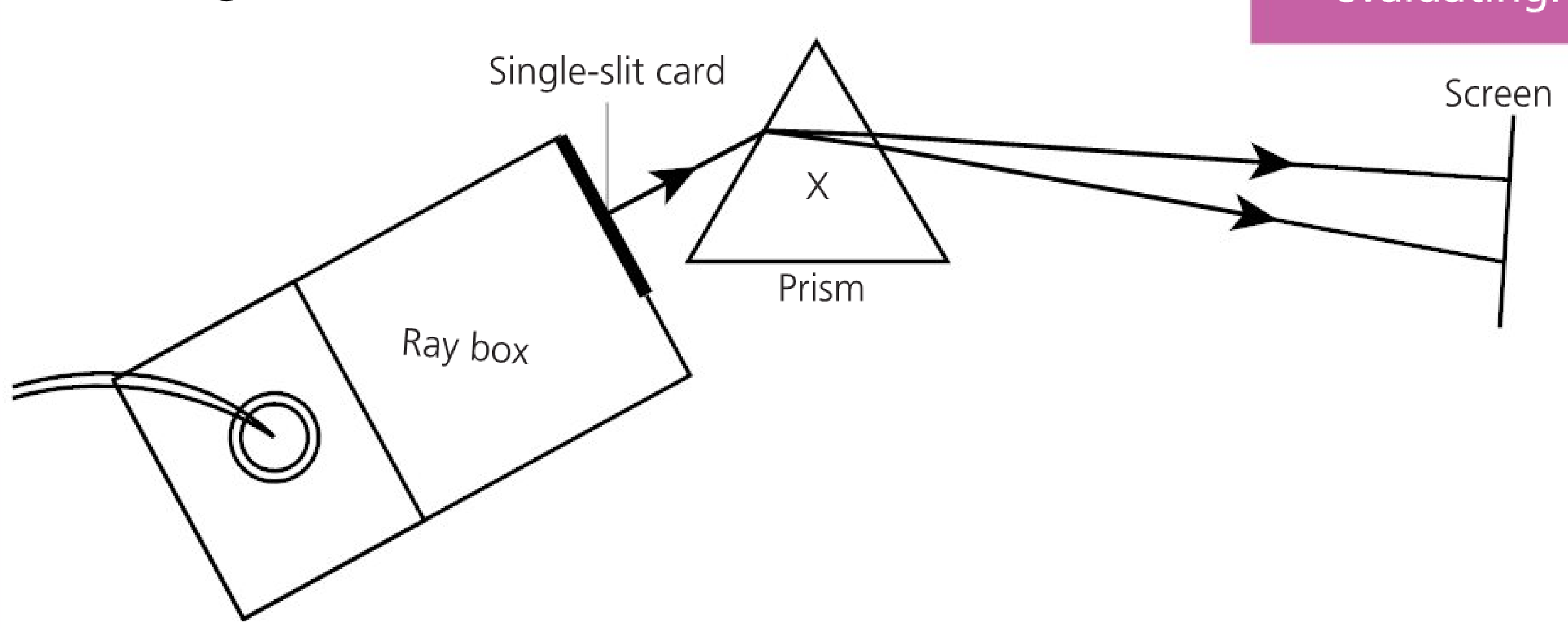
Use a pencil to mark off the beginning and end of the transmitted spectrum for each filter. **Annotate** any colours visible in the transmitted spectrum.

Analysis

Since the angle of diffraction or refraction depends on the wavelength of the incident light, the width of the spectra you see on the screen is proportional to the bandwidth of the colours transmitted. **Outline** the bandwidths observed for each of the colours and **comment** on the different bandwidths you have measured.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion C: Processing and evaluating.



■ **Figure 10.16** Experiment set-up for measurement of bandwidth of filters

How do the Earth's systems interact with each other and with surrounding space?

You should be aware that magnetic fields form around certain materials. You will be aware that Earth, too, has a magnetic field around it, as we explored in *MYP Sciences by Concept 1:* Chapter 6. The direction of Earth's magnetic field defines a north **magnetic pole**. The actual magnetic pole is some 800 km away from the **geographic north pole** and falls in Canada, although it has moved at different points in the geological past and there is even evidence that it has completely switched direction 171 times in the last 71 million years.

It is thought that the Earth has a magnetic field because the liquid iron in the Earth's core circulates as the Earth spins on its axis. This motion generates an electric current which in turn produces the magnetic field. The Earth's magnetic field is not just a useful way to find your way around, however. As Figure 10.17 shows, it extends out into space and protects us from the constant stream of electrically charged particles that come from the Sun and from objects in deep space such as supernovae or neutron stars.

The magnetic field deflects most of these particles away from the Earth, although those approaching along the line of the Earth's **equator** can become trapped in the field and then channelled towards the polar regions. When these particles enter the atmosphere, they cause ionization of atmospheric gases and this produces the spectacular fields of light known as aurorae.

Figure 10.18 Aurorae caused by charged particles in the Earth's thermosphere

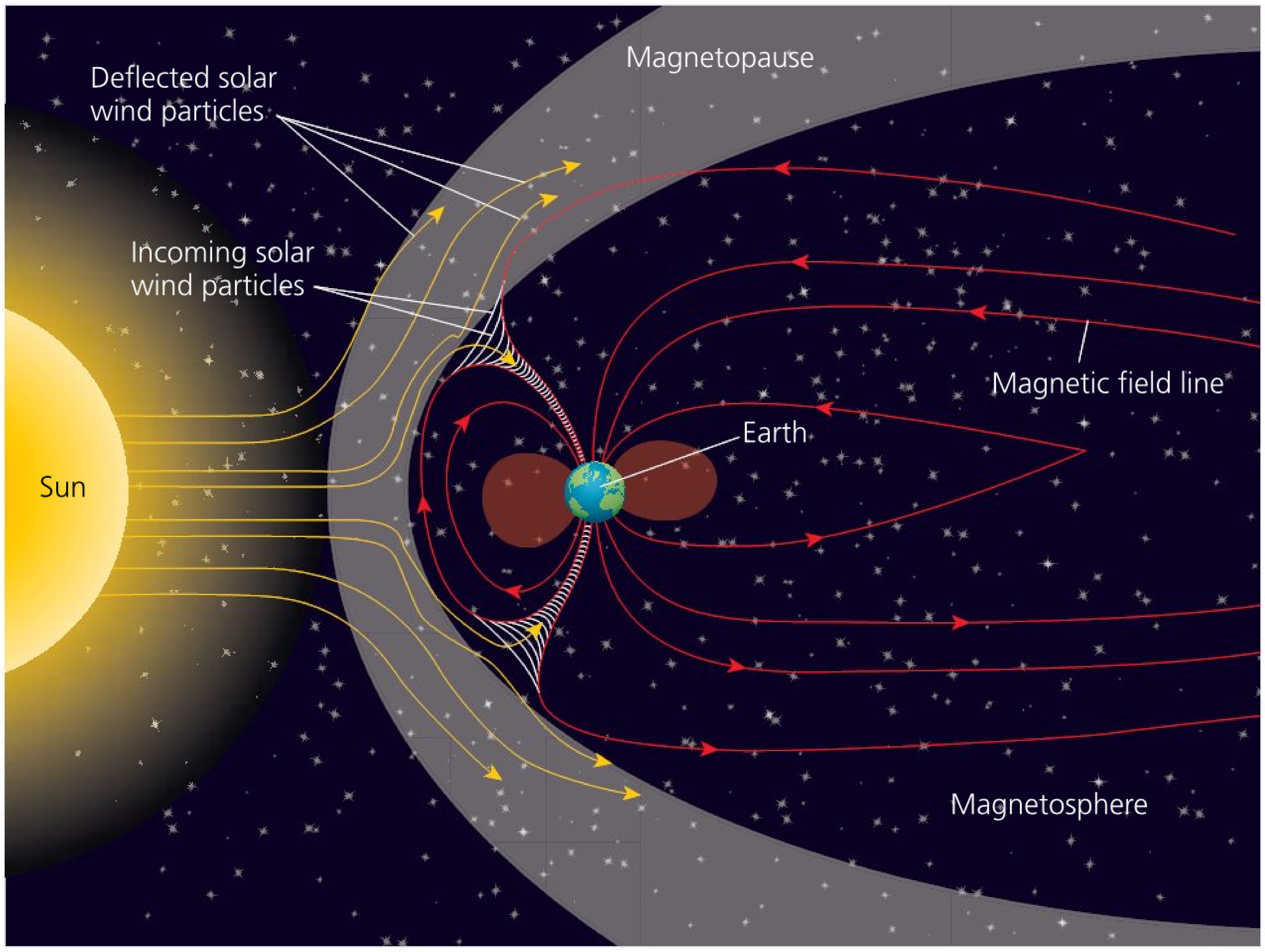


Figure 10.17 Earth's magnetic field protects us from charged particles from space

EXTENSION

In 1992 the first scientifically accepted evidence was found that other stars in the Universe had their own planetary systems, called exoplanets or extra-solar planets. Find out how scientists have detected these planets orbiting very distant stars. A good starting point for your research is: https://exoplanets.nasa.gov/

How have cosmological models changed our perspective?

As we saw in Chapter 2, the most influential force acting on masses over long distances in space is gravity. It is gravity which determines the fundamental forms and geometry of the Universe, whether way out in deep space or in our own spatial neighbourhood. The Sun's gravity is the most significant influence in our own Solar System. The Solar System consists of many different kinds of objects, but all of them are bound into **orbits** by the Sun's gravitation. The objects themselves all exert gravitational force on each other and this can lead to changes or **perturbations** in their orbits; Jupiter, the most massive of the planets, is particularly important in this respect.

The more we learn about the Universe, the more we come to rethink our own place in it. In the past many people assumed that the Earth was flat, since it looked that way, until Eratosthenes (276–194 BCE) estimated the circumference of the Earth using the elevation of the Sun at noon in Alexandria and in Syene (now Aswan). In 1492 Christopher Columbus used this estimation to justify his voyage to Asia, accidentally running into the 'New World' of the Americas instead. For a long time it was generally held in Europe that the Earth was at the centre of the Universe, with planets and the Sun orbiting around it. This **geocentric view** derived from the astrological cosmology of Ptolemy of Alexandria (*d.*168 CE).

By the time of Galileo Galilei's birth in 1564, the idea that the Earth was spherical was well established in Europe, but the idea that the Sun was at the centre of things was still controversial. The claim had been made by a Polish astronomer, Nicolaus Copernicus (1473–1543), based on observations of the motion of planets. In the early 1600s, Galileo used his homemade telescope to make observations of the Moon and gazed on a whole new world. When he turned to the planet Jupiter, his observations showed four points of light moving from one night to the next, and he realized that he was observing a system of moons orbiting the planet. This convinced him that Copernicus had been right; surely, if Jupiter were the centre of the 'cosmos' for these moons, then the Sun could be at the centre of ours.

Appearances can be deceptive

While science relies on observations to make preliminary hypotheses about the Universe, not any old observation will do; the observations we make have themselves to be selected so as to suggest a relationship between key variables. The relevant variables are chosen through having a 'working idea' – or hypothesis – about the phenomenon to be investigated. Some philosophers have argued that a scientist's first working idea is really no more than an imaginative guess!

Johannes Kepler (1571–1630) refined the **heliocentric** model still further, using careful observations made by the astronomer to the Danish royal court, Tycho Brahe (1546–1601). Kepler elaborated three important laws in which he showed that Brahe's observations could best be explained using elliptical orbits for the planets.

In the geocentric view, the Sun and the planets had been held in place by slowly rotating crystal spheres arranged concentrically around the Earth. Now Kepler's realization that the orbits of the planets were not spherical but *elliptical* meant this idea would not work. So what was holding the planets in their orbits?

GRAVITATION

Kepler's laws showed that the further out we go, the slower the planets orbit (Table 10.3). In 1684 Isaac Newton suggested that the 'something' that held planets in their stately orbits was a force, which he named **gravitation**.

Planet	Mean orbital radius/AU	Orbital time period/years
Earth	1.0	1.00
Mars	1.5	1.88
Jupiter	5.2	11.9

■ **Table 10.3** Values for the mean orbital radius and time period for three planets

This 'gravitation' was hard to accept. It was unseen, but its effects were indisputable – you may have heard the story that Newton's inspiration was when he was woken from a nap under an apple tree by a gravitationally influenced apple. What was more, gravitation acted between all masses and everywhere. Newton used Kepler's work to formulate his law of universal gravitation (see Chapter 2).

Newton's law of universal gravitation follows as a consequence of the second law of motion. Any object moving in a circle is changing direction constantly. As we saw in Chapter 7, a change in direction means a change in velocity and this in turn means acceleration must take place. While the inertia of the object means it would usually continue in a straight line (as Newton's first law describes), instead the object is 'moving' as though it were trying to reach the centre of the circle, so the acceleration is directed *inward*.

Newton's second law ($F = ma$) tells us that a force is required to produce this acceleration and the force is in the same direction: *inwards* towards the centre of the circle. This force is called **centripetal force**.

When an object orbits around a gravitational mass such as the Earth, it is pulled towards the centre of the Earth by the centripetal force provided by its weight. If the object is moving quickly enough, the Earth's surface will curve away from it by a distance equal to its fall, and so the object effectively stays in an orbit in a state known as **freefall**.

ACTIVITY: Massive force

■ ATL

■ Critical-thinking skills: Draw reasonable conclusions and generalizations

Use the data in Table 10.4 on planetary masses, some suitable **estimates** and Newton's law of universal gravitation to **calculate**:

- **the gravitational force of the Moon on the Earth**
- **the gravitational force of the Earth on the Moon**
- **the gravitational force of your science teacher on you.**

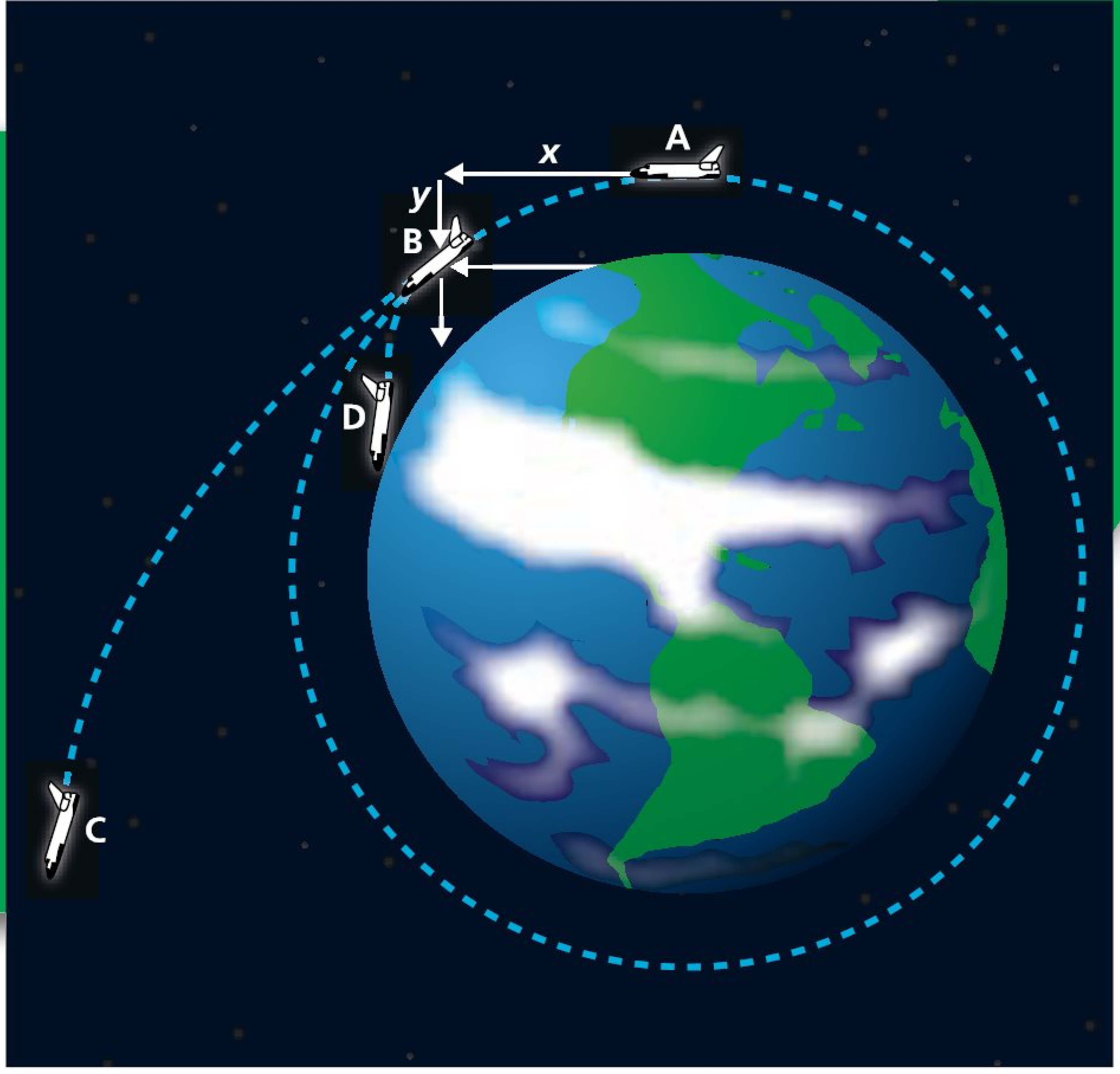
Mean Earth–Moon distance/m	3.8×10^{8}
Mass of Moon/kg	7.3×10^{22}
Mass of Earth/kg	5.9×10^{24}

■ **Table 10.4**

Comment on the relative sizes of these forces.

◆ Assessment opportunities

◆ In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.



■ **Figure 10.19** The spacecraft stays in a circular orbit between A and B. In travelling the tangential distance *x*, it falls a distance *y* towards the Earth's surface, but the Earth's surface curves away from the spacecraft at an equal distance *y*. To reach C, the spacecraft needs to increase its tangential velocity and leave circular orbit. To land via D, the spacecraft would decrease its tangential velocity.

EXTENSION

The Earth is ringed by many thousands of artificial satellites that we have launched over the period since Sputnik 1, the first human-made satellite sent into space by the Soviet Union in 1957. Find out about how satellites in different kinds of orbits are used for different purposes using these search terms: **polar orbit, geostationary orbit, global positioning network, meteorological satellite, communications satellite, spy satellite**.

THINK–PAIR–SHARE

Think: What answers can you think of for these questions? How many stars are there in an infinite Universe? How long have they been shining?

Discuss in pairs: what does Newton's idea of an infinite, static Universe suggest the night sky *should* look like?

Share your ideas in class. Now suggest as many ways as you can think of to explain the fact that the night sky is mostly dark.

■ **Figure 10.20** Hubble deep-space view

THE LONGEST VIEW

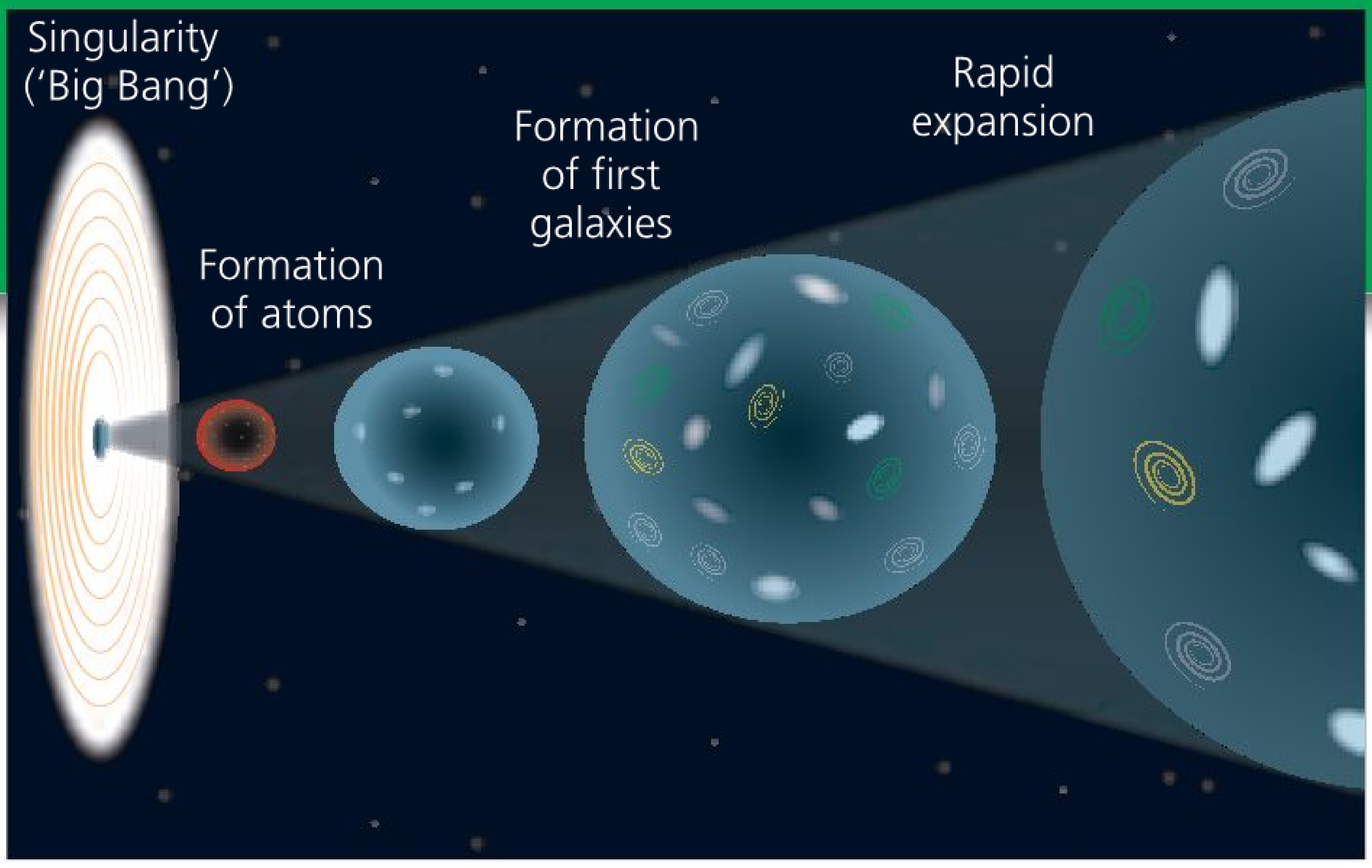
Isaac Newton believed that the Universe was static, infinite and homogeneous; that is, nothing in it was changing, it went on forever and it was the same in every direction. But this view can be challenged with another simple question: why, then, is the sky dark at night? This question is called **Olber's paradox**.

RED-SHIFT

In 1928, an astronomer called Edwin Hubble (1889–1953) made an amazing discovery. He was observing the spectra of some different stars, but noticed something surprising. It seemed that the spectrum of light from hydrogen in the stars was different from that seen for hydrogen on Earth.

Hubble thought that he had made a mistake, but when he checked his measurements he realized something: the amount by which the wavelengths of hydrogen from stars was 'shifted' (changed) was proportional to the distance of the stars from us. Hubble made a leap of imagination and suggested that this could only be explained by the Doppler effect, which changes the wavelength of waves when an object is moving. Hubble realized that light waves could also be Doppler-shifted. The strange thing was that all of the measurements he made suggested the lines were **red-shifted**, or moved towards a longer wavelength. This implied that everything was moving *away* from everything else.

■ **Figure 10.21** Red-shifted spectra



■ **Figure 10.22** Expanding Universe

THINK–PAIR–SHARE

Think: What answers can you think of for these questions? In a Universe of a finite age of 13.8 billion years, what is the furthest distance we can see? **Suggest** what this means about our knowledge of the Universe. **Explain** your answer.

Discuss in pairs: how does the expanding Universe theory resolve Olber's paradox?

Share your ideas in class.

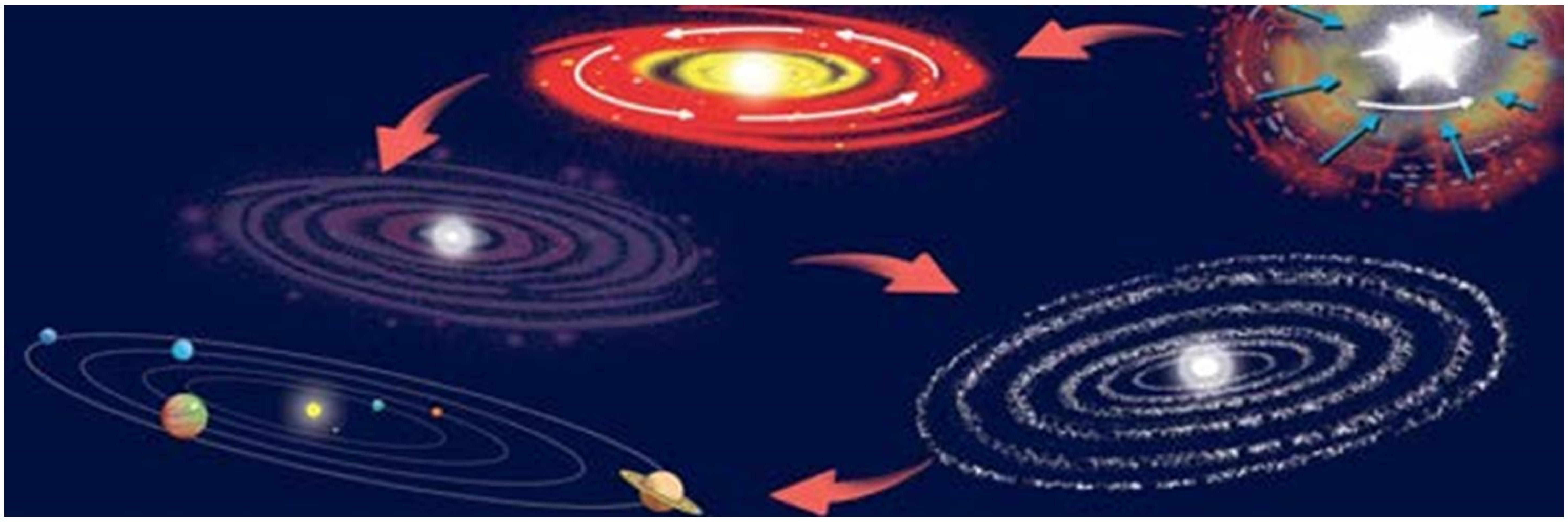
Hubble and other scientists deduced that the Universe was expanding. But that in turn led to another very strange thought: if the Universe was expanding, then it must have started out very small ... in fact it must have started out infinitely small!

THE BIG BANG THEORY

The theory that was elaborated from Hubble's observations is known as the **Big Bang theory**. In the theory, the Universe is neither infinite nor static; rather it began as a point and has been expanding for an estimated 13.8 billion years. It is important to recognize that the theory does not suggest that all the *matter* in the Universe was squeezed into one place in empty space, rather that all of *space* was only a single point. Just as a balloon expands and stretches as we inflate it, space is itself expanding and 'stretching', full of matter and energy. At the very beginning, the density of the Universe was unimaginably high and so was its temperature. The conditions in the first nanoseconds of time were so extreme that matter itself did not exist as we currently know it.

The early Universe was both violent and oddly uninteresting, consisting only of gaseous light elements (hydrogen) and energy. But as space–time expanded, so the energy in the Universe was distributed through more and more space and this meant that – across unimaginably great periods of time – gravity became a more significant influence on matter. Slowly, atoms would be attracted to each other and matter began to join to form denser regions of gas as **stellar nebulae**, with relatively 'empty' space between them. Within the nebulae, the gas achieved still greater density until nuclear fusion could initiate and the first stars were born.

With still more time, some of those stars would have produced heavier elements in their cores through nucleosynthesis and ejected that material into space when they went nova. Our own Solar System is thought to have been formed around 4.6 billion years ago from a stellar nebula consisting of gas and dust of this kind. The Sun formed at its centre, where gravitation produced the greatest densities, but further out in a rotating disc of material 'eddies' and currents produced smaller **accretions** of matter which would ultimately produce the planets (Figure 10.23).



■ **Figure 10.23** The disc-accretion model for the formation of our Solar System

What are the systems that make the Earth work?

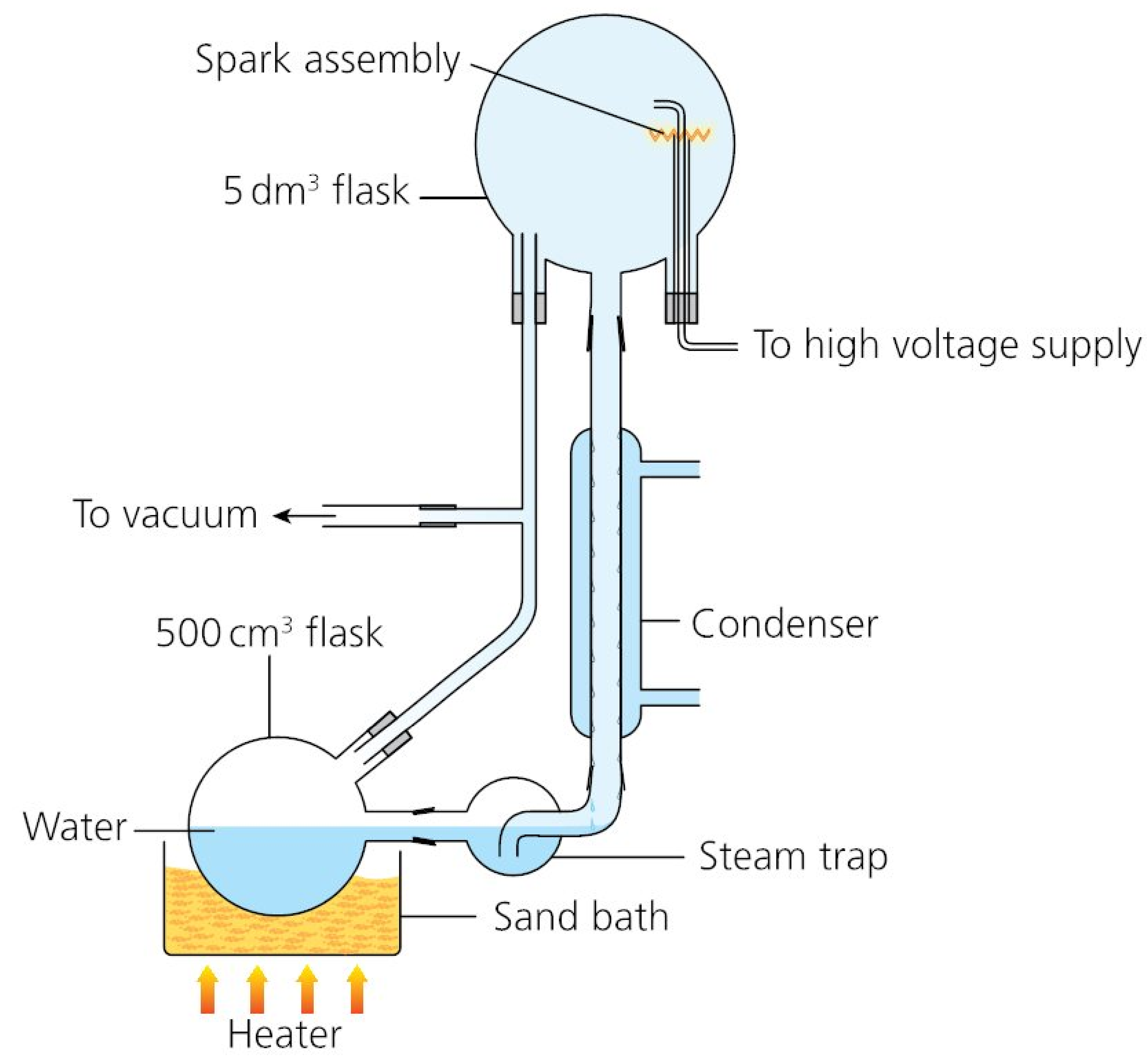
The Earth's early years were violent. About 4.5 billion years ago, a body about the size of Mars collided with Earth. The force of the impact caused the surface to partly liquify and molten debris to be ejected into space. This eventually combined to form our Moon. For the next billion years, the Earth and other planets were bombarded by asteroids. This kept the Earth as a boiling sea of molten rock and volcanically active. It was only when these collisions stopped that the Earth was able to cool down and form a thin crust on its surface. This crust and the layer beneath, the mantle, is what we refer to when we talk about the **lithosphere**. The lithosphere is still constantly changing. (See *MYP Sciences by Concept 1*: Chapter 6 to revisit the structure of the Earth, plate tectonics and different types of rock.)

At first, this surface was barren and lifeless. The first atmosphere consisted of the gases emitted from volcanic eruptions: mainly carbon dioxide but also hydrogen sulfide, methane, ammonia and water vapour. About 2.7 billion years ago, the Earth was cool enough for the water vapour to condense into oceans (creating our hydrosphere). With the Sun only about 70 per cent as bright as it is today, the thick layer of carbon dioxide (and methane) in the atmosphere prevented the Earth from freezing over.

Scientists have found evidence for the first existence of oxygen during this period; its source was microscopic organisms called cyanobacteria (the first components of the biosphere) that started to fill the Earth's oceans and obtained their energy by photosynthesis. The oxygen built up in the atmosphere until eventually there was enough to start removing methane. Carbon dioxide was also being removed from the atmosphere; it was being locked in sedimentary rocks and dissolving in the oceans. About 2 billion years ago, the methane haze cleared and the bacteria evolved to form plants. The oxygen also reacted with ammonia to form nitrogen and about 1 billion years ago, led to the formation of ozone which was vital for filtering out harmful UV radiation. Until then, life was only possible in the oceans.

This 'oxygen boom' started about 700 million years ago and enabled the evolution of species that could use oxygen to create energy. Finally, about 400 million years ago, life moved to the land.

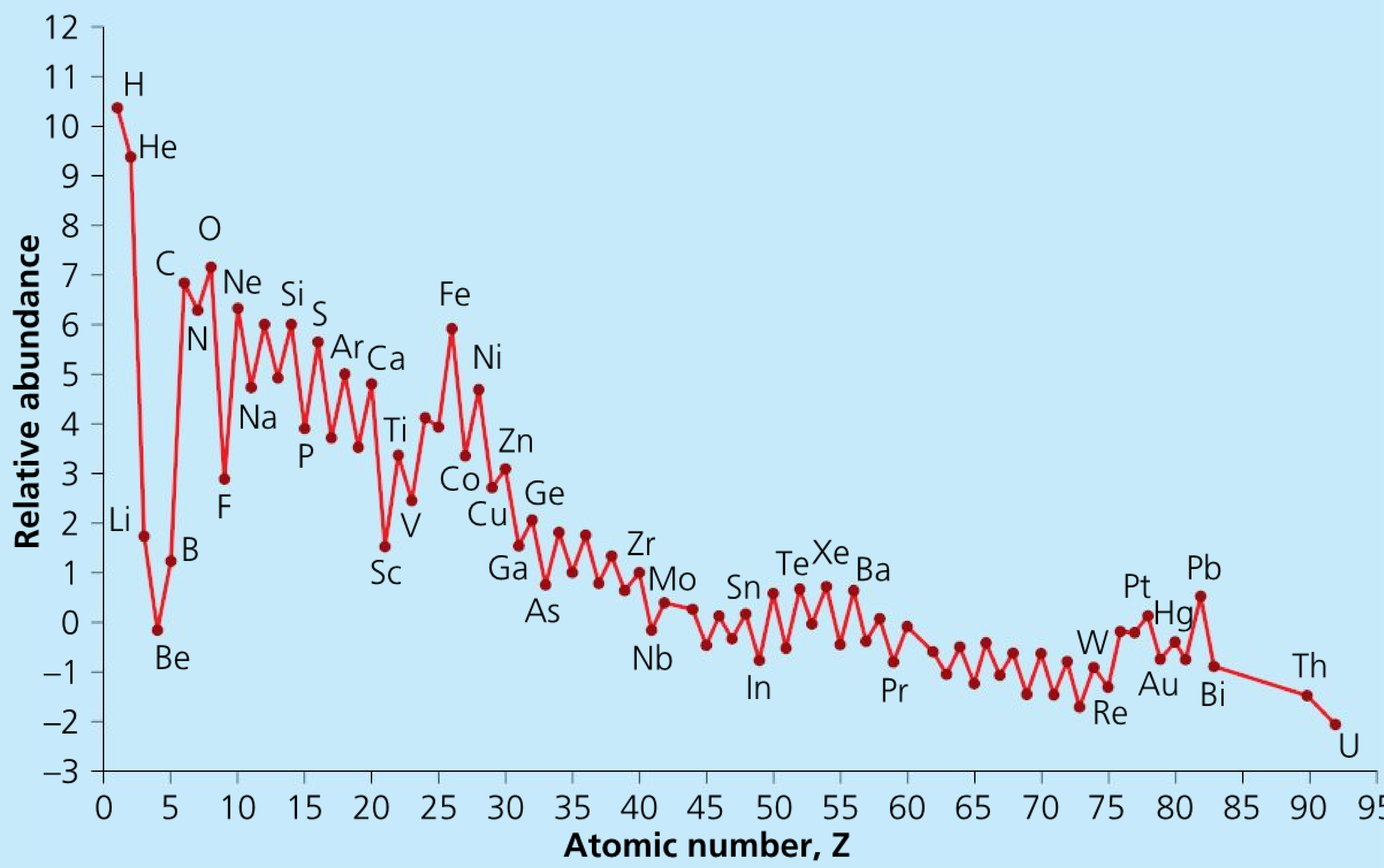
So how did we go from simple chemistry, atoms and molecules, to living cells? One of the theories behind this 'transition' to a biosphere arises from the Miller–Urey experiment, where the two scientists managed to create a 'primordial soup' – a solution that contained organic compounds from which life is thought to have originated. Recreating the conditions in the Earth's early atmosphere, they exposed a mixture of methane, concentrated ammonia, hydrogen, carbon dioxide and nitrogen to electrical sparks (that represented lightning) and after a few days, found traces of amino acids.



■ **Figure 10.24** The Miller–Urey apparatus

MEET A SCIENTIST: MARIA GOEPPERT MAYER

Maria Goeppert Mayer was born in Germany in 1906. She completed her PhD at the University of Göttingen where she met her husband, an American physical chemist, Joseph Mayer, and moved to the United States. She had to work as a volunteer in order to remain **knowledgeable** in the field of physics, since no university would consider hiring a woman. After the Second World War, she was finally hired at the University of Chicago as a professor (without pay) where she started to work on a project to determine the origin of the elements. Her **inquiring** nature led her to wonder about why hydrogen (atomic number 1) was the most abundant element in the Universe, helium (atomic number 2) the second most abundant but lithium (atomic number 3) was not the third most abundant (see Figure 10.25). Through her experiments she discovered that elements with a certain number of protons or neutrons were more stable and called these numbers (2, 8, 20, 28, 50, 82, 126) 'magic' numbers. The nuclear shell model she proposed was also proposed independently by a scientist in Germany, with whom she shared a Nobel Prize in Physics in 1963.



■ **Figure 10.25** The relative abundance of elements in the Universe

ACTIVITY: My, how you've changed!

ATL

- Communication skills: Interpret and use effectively modes of non-verbal communication
- Collaboration skills: Help others to succeed; Listen actively to other perspectives and ideas; Encourage others to contribute

Work with a learning partner to answer the questions below.

1. **Create a timeline to represent the evolution of the Earth's atmosphere.**
2. **State the composition of the Earth's atmosphere today. Explain how the percentage of carbon dioxide in the early atmosphere decreased and oxygen and nitrogen increased.**
3. **Formulate balanced symbol equations for the reactions that reduced the amounts of methane and ammonia in the early atmosphere:**
   a. **methane reacted with oxygen to form carbon dioxide and water**
   b. **ammonia reacted with oxygen to form nitrogen and water.**
4. **Describe how Miller and Urey mimicked the conditions of the early atmosphere to see whether they would lead to the formation of complex molecules.**
5. **Discuss the validity of the Miller–Urey experiment in representing the beginning of life on Earth.**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

ACTIVITY: How much oxygen?

ATL

- Critical-thinking skills: Practise observing carefully in order to recognize problems; Evaluate evidence and arguments; Draw reasonable conclusions and generalizations
- Creative-thinking skills: Apply existing knowledge to generate new ideas, products or processes

There are a number of experiments that can be carried out in the lab in order to measure the percentage of oxygen in the air today. In this activity you will carry out one of these experiments and **suggest** how it could be modified to form another.

Equipment and materials (per group)

- Glass crystallizing basin
- 100 cm^3 glass measuring cylinder
- Small candle on 15 mm diameter rubber bung
- Wooden splint
- Lighter
- 30 cm ruler

Safety: Safety goggles should be worn. Hair should be tied back as a Bunsen burner will be used.

Method

1. **Measure** 100 cm^3 of water in the measuring cylinder and pour it into the crystallizing basin.
2. Sit the candle on the rubber bung and place the bung in the centre of the crystallizing basin, in the water. The water level should be below the top of the bung.
3. Place the measuring cylinder upside down in the centre of the crystallizing basin, making sure it stands unsupported and the spout of the measuring cylinder is fully submerged.
4. Use a permanent marker to mark the level of the water on the side of the inverted measuring cylinder.
5. Remove the measuring cylinder carefully, making sure not to knock over the candle or drip water onto it.
6. Light the candle with the wooden splint and lighter.
7. Invert the measuring cylinder. Place it over the candle and bung quickly (Figure 10.26).
8. Watch what happens and record your observations.
9. Use a permanent marker to mark the new level of the water on the side of the inverted measuring cylinder.
10. Remove the measuring cylinder; **measure** the distance from the base of the measuring cylinder to the initial point that you marked (length of the air column) and to the distance that the water level moved during the experiment.

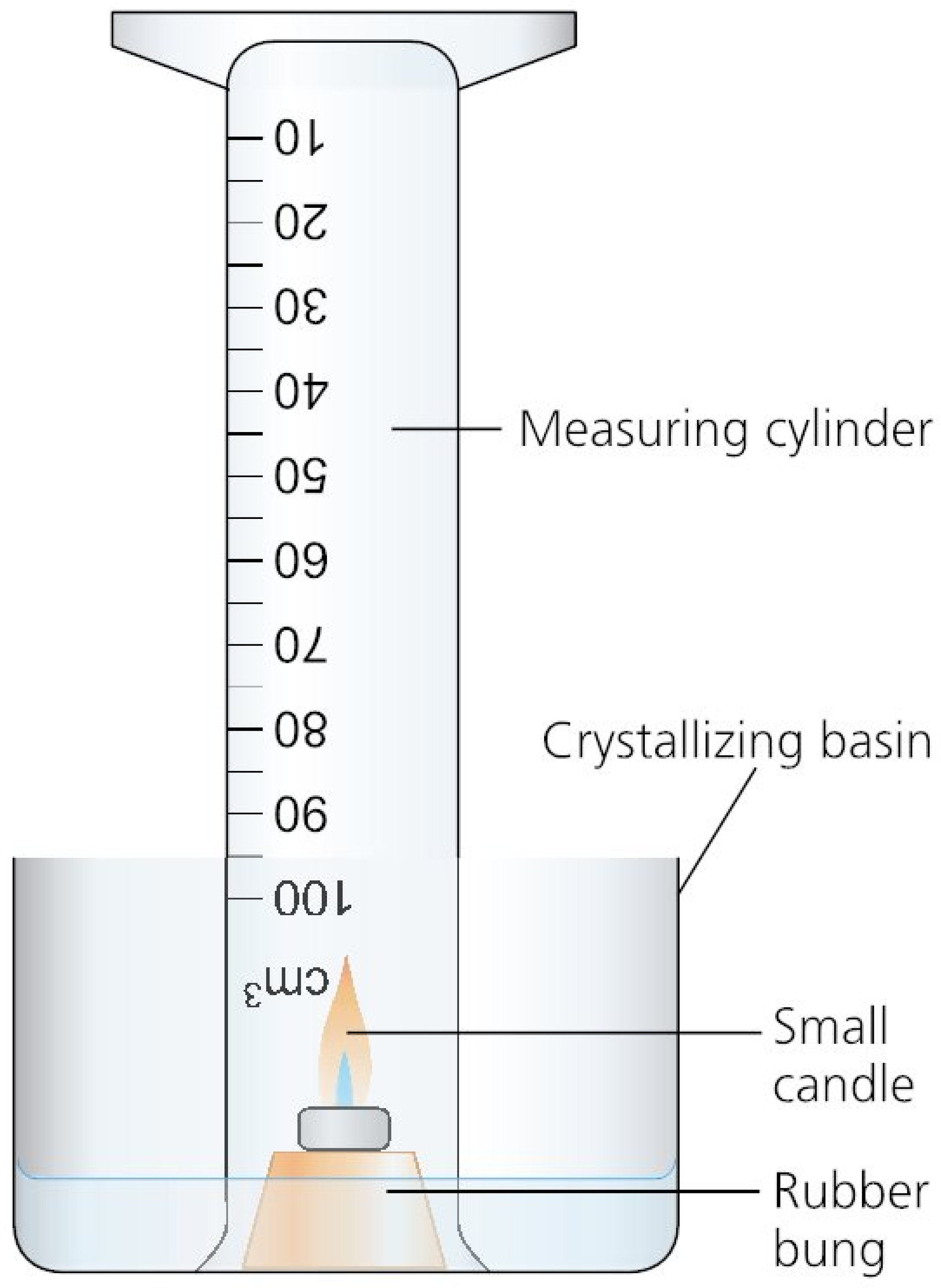


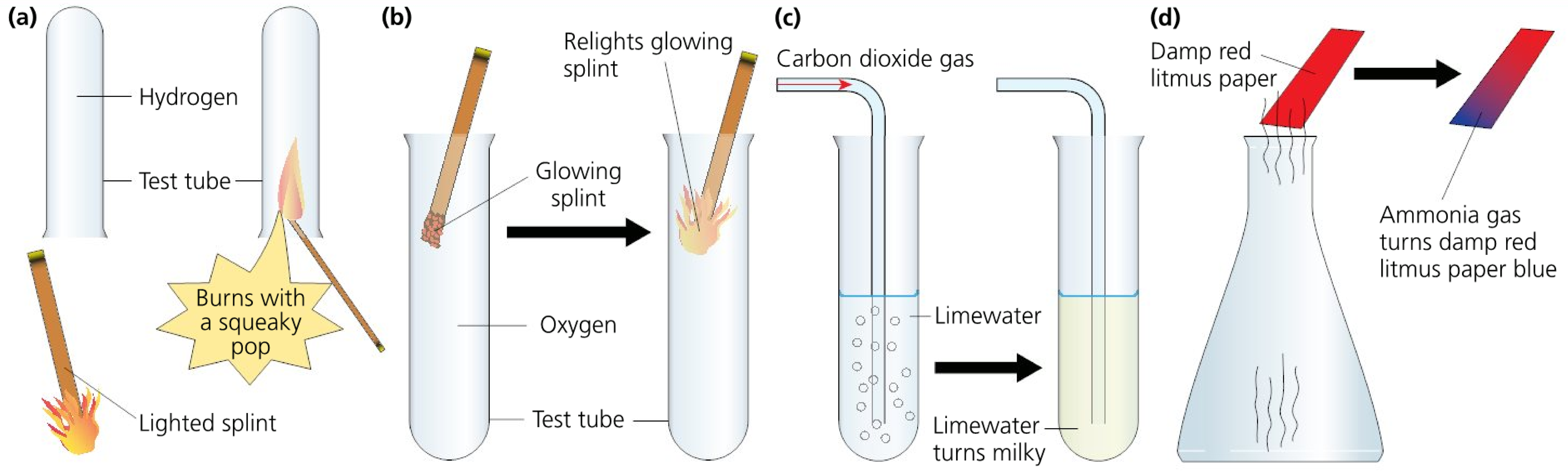
Figure 10.26 Experimental set-up

Analysis

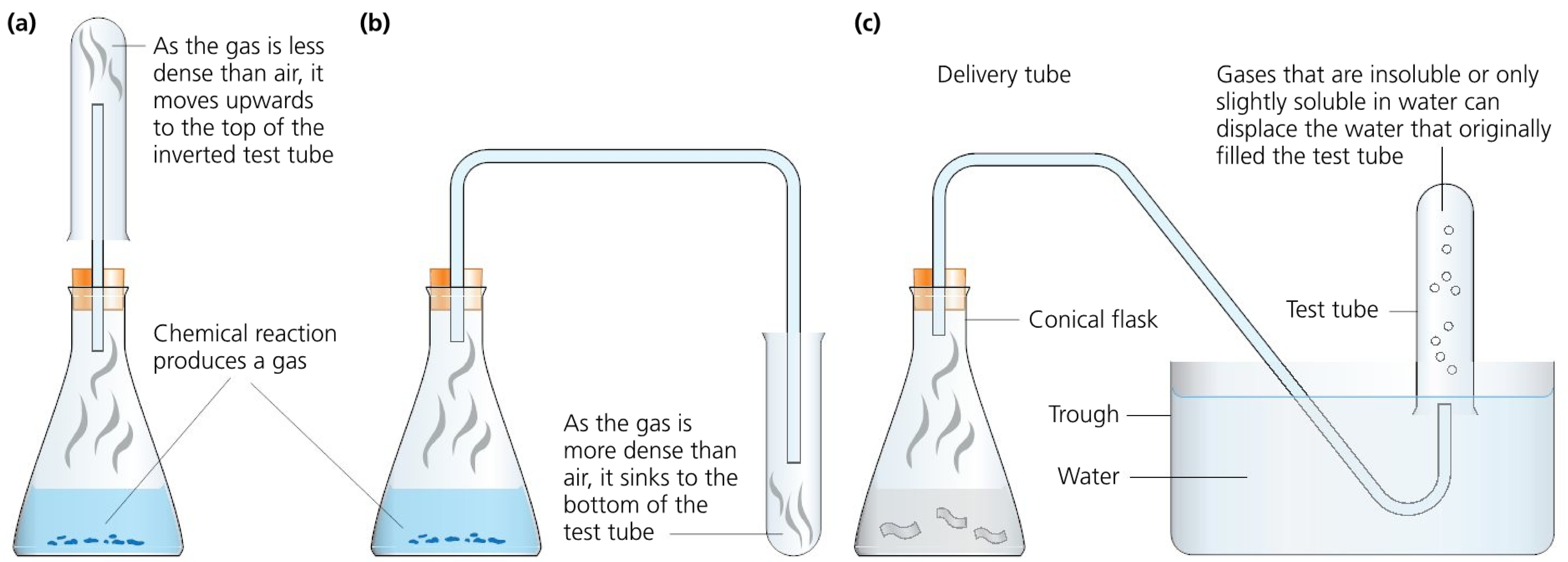
1. **State** what percentage of the total air oxygen should have represented in the inverted measuring cylinder before the experiment was started.
2. **Calculate** the percentage change in the volume of air. **Compare** your values to the actual percentage of oxygen in air.
3. **Explain** the process that leads to a change in the water level.
4. **Describe** why the candle went out. **Suggest** two ways that this could affect the accuracy of this method.
5. **Suggest** how this method could be modified using the oxidation of a metal such as iron wool. **Outline** how the experiment would be carried out and **discuss** any advantages this approach might have.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion C: Processing and evaluating.



■ **Figure 10.27** Gas tests for (a) hydrogen, (b) oxygen, (c) carbon dioxide, (d) ammonia



■ **Figure 10.28** Collection of gases by (a) upward delivery, (b) downward delivery and (c) over water

Figure 10.27 shows tests for four key gases.

How you collect the gas depends on its properties. There are three different ways to collect gases in a lab, shown in Figure 10.28: upward delivery, downward delivery and collection over water.

Gases that are less dense than air will naturally rise up through the air when they are produced. By collecting the gas in an inverted test tube, the gas will move up through the test tube, displacing the mixture of air as it does so.

Gases that are more dense than air will naturally sink in air. By collecting the gas in a normal upright test tube, the gas will sink to the bottom of the test tube, displacing the mixture of air as it does so. It is not necessary to cover the top of the test tube as the dense gas will not rise.

Insoluble gases can be bubbled into inverted test tubes/measuring cylinders filled with water. As the gas fills the test tube/measuring cylinder, the water is displaced.

The solubility of gases has played an important role in the existence and evolution of our biosphere. We have an atmosphere that can support life because significant amounts of carbon dioxide were removed from the early atmosphere as it dissolved in the oceans. Life was able to move from sea to land because the oxygen produced by the first photosynthesizing organisms did not dissolve completely in the oceans, and escaped into the atmosphere, where it removed the methane and formed the ozone layer. In these examples we see connections between the different spheres as substances moved from one sphere to another.

But perhaps two of the most important examples of how the spheres are connected are the carbon and nitrogen cycles. These cycles show how the elements carbon and nitrogen, both of which are vital in the biosphere, move between the spheres in different forms.

DISCUSS

Find out about the densities and solubilities of the gases shown in Figure 10.27 and so **suggest** the best ways to collect them.

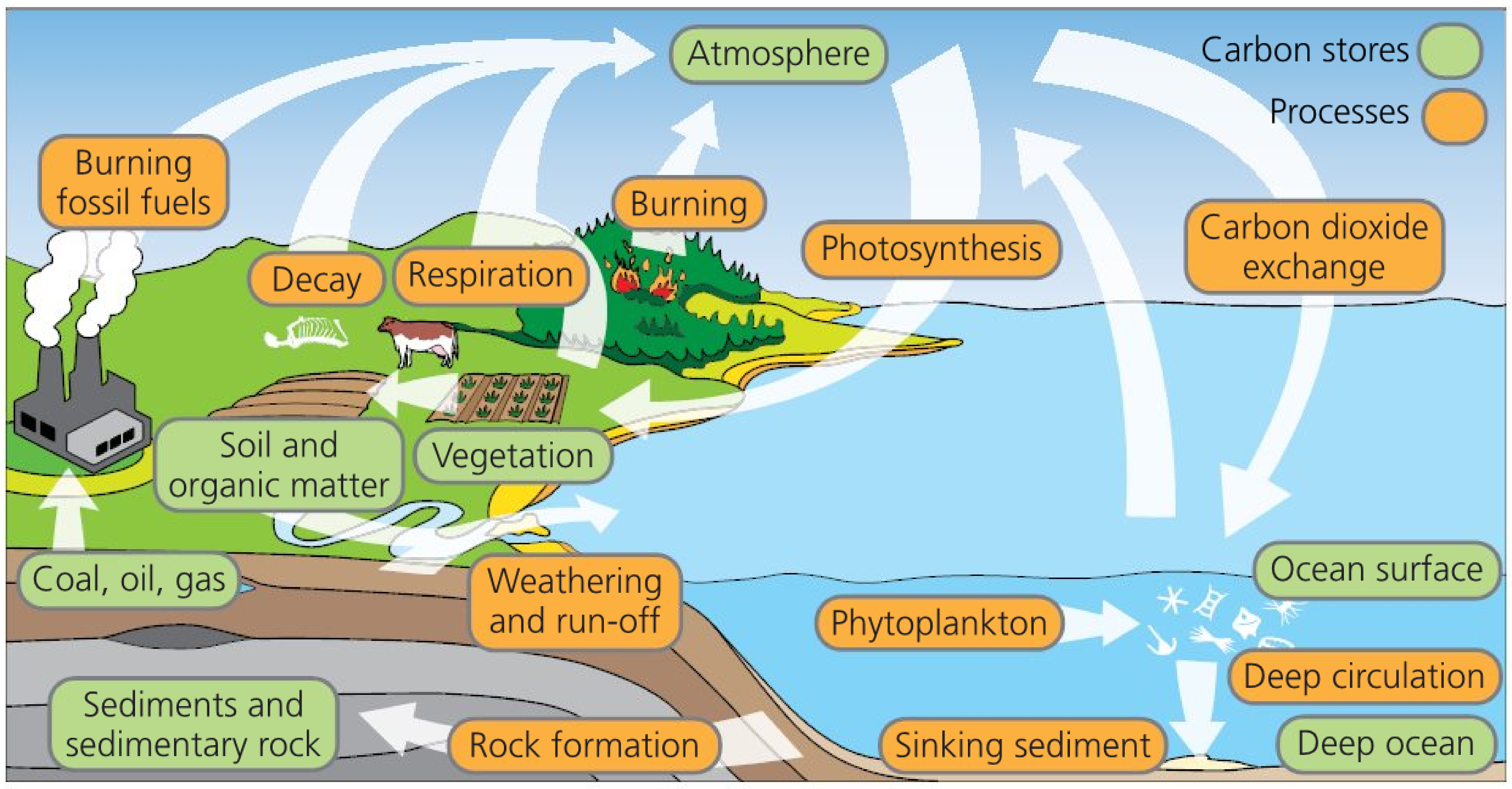
ACTIVITY: The carbon and nitrogen cycles

ATL

- Critical-thinking skills: Interpret data; Revise understanding based on new information and evidence
- Communication skills: Interpret and use effectively modes of non-verbal communication; Make inferences and draw conclusions

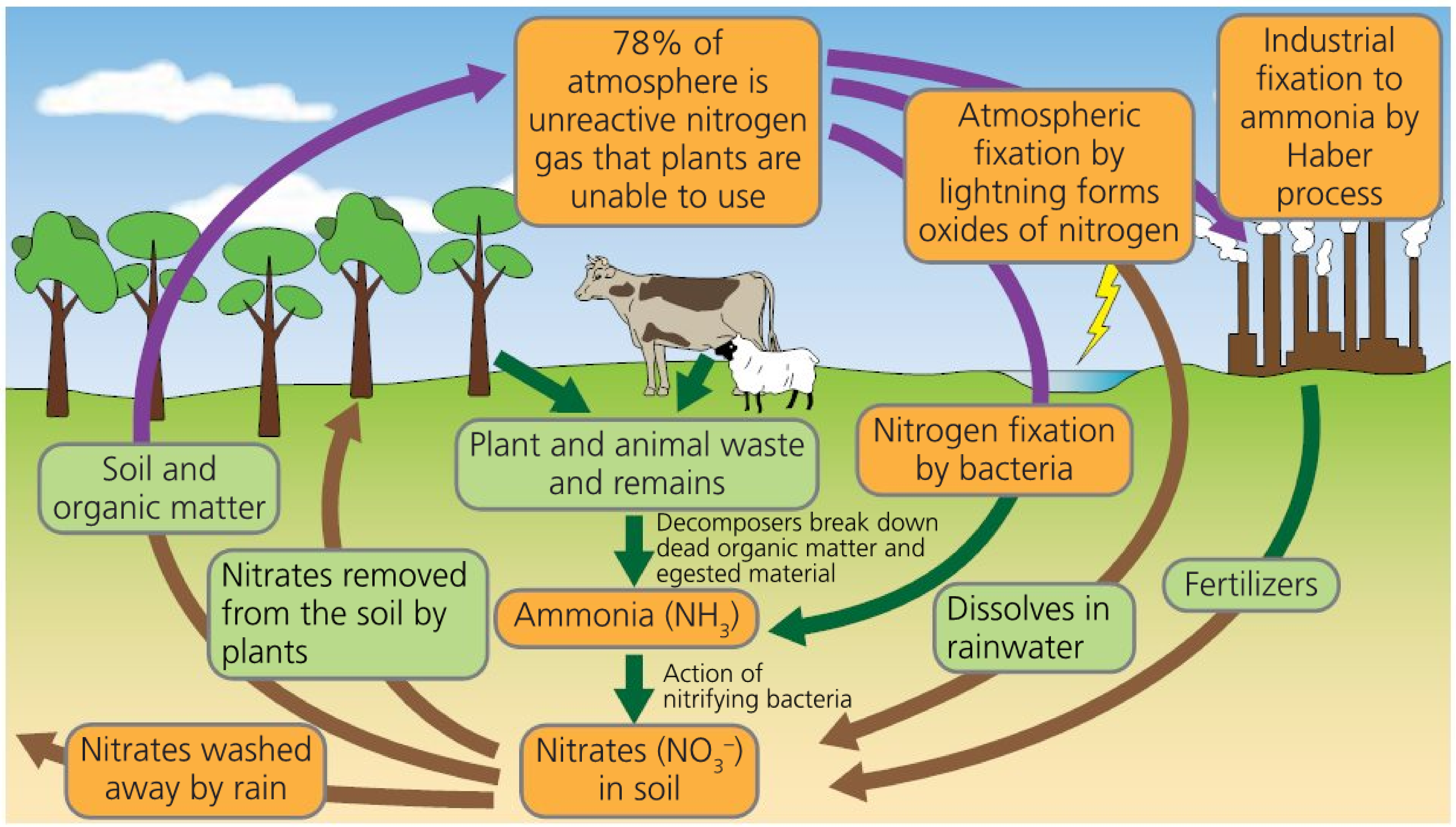
The carbon cycle

1. **Identify** which spheres carbon is found in, giving an example of its form in each one.
2. A source in a system is considered the origin of a component. **Identify** natural sources of carbon in the carbon cycle.
3. A sink in a system is the destination of a component. **Identify** carbon sinks in the carbon cycle.
4. **Outline** the processes that remove carbon dioxide from the atmosphere.
5. **Outline** the processes that increase the amount of carbon dioxide in the atmosphere.
6. **Formulate** balanced symbol equations for the chemical reactions photosynthesis, respiration and the combustion of an alkane.
7. Carry out some research in order to **define** the process of decay. **State** the name of the microorganisms involved. **Outline** the conditions that will encourage and speed up decay.
8. Search the slow carbon cycle to **describe** two ways in which sedimentary rock is a sink of carbon.
9. **Create** two separate chains that both start with the Sun: one that ends as carbon dioxide in the atmosphere as a result of respiration in humans and one that ends as a fossil fuel.
10. **Describe** the effect of deforestation on the carbon cycle.
11. One additional sink of carbon is in calcium carbonate. Molluscs combine calcium and carbonate ions (from dissolved carbon dioxide) to form calcium carbonate, which creates their shells and on which they rely for protection. One potential effect of global warming is an increase in the acidity of the oceans (more on this in Chapter 11). Using your knowledge of reactions of carbonates, **suggest** how the carbon cycle might be affected by increasing ocean acidity.



■ **Figure 10.29** The carbon cycle

The nitrogen cycle



■ **Figure 10.30** The nitrogen cycle

With reference to Figure 10.30 and your own research, **summarize** how nitrogen moves between the atmosphere, biosphere and lithosphere.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

How do we make use of the Earth's natural resources?

■ **Figure 10.31**

SEE–THINK–WONDER

Consider the images in Figure 10.31 in the context of the chapter inquiry question. What do you **see**? What do you **think** about that? What do they make you **wonder**?

Humans have always relied on natural resources from all the spheres of the Earth for survival. Unfortunately, today we extract these natural resources at too fast a rate and in ways that are **unsustainable**. The shift from using to exploiting natural resources began with the Industrial Revolution in the late eighteenth and early nineteenth century, with new technologies making the processes of obtaining the resources easier and faster. As population increased, so did energy demands and with the boom of the electronic age from the 1950s onwards, our focus has been on creating materials that make our lives more convenient. But what is this doing to our natural world?

In Chapter 5 we explored some of the impacts of extracting and burning fossil fuels. Now we will focus on the impact of obtaining natural resources from the air and the lithosphere, considering the processes of separation of air and the extraction of metals, respectively.

SEPARATING AIR

Air contains approximately 78 per cent nitrogen and 21 per cent oxygen. Being able to separate pure, clean samples from the air provides us with an essentially unlimited resource of each. But what are the consequences associated with this process? Find out in the activity *Packaging gases*.

EXTRACTION OF METALS

The first 92 naturally occurring elements can be found in varying quantities in the lithosphere. As we saw in *MYP Sciences by Concept 2:* Chapter 2, the form in which they exist depends on the reactivity of the metal. Metals that are unreactive exist as pure metals called **native metals**, but most exist in the form of compounds in **ores**.

Before we look at extraction processes, review how we can determine the reactivity of metals.

■ **Figure 10.32** Common ores. Find out what element can be extracted from each.

ACTIVITY: Packaging gases

ATL

- Communication skills: Take effective notes in class; Make effective summary notes for studying
- Critical-thinking skills: Draw reasonable conclusions and generalizations; Consider ideas from multiple perspectives

Watch this video produced by the Royal Society of Chemistry: **www.youtube.com/watch?v=5ECw-_q90-Q**

1. **State the names of the gases in the air used by BOC. Identify some of their uses.**
2. **A flow diagram of the separation process is shown in Figure 10.33. Copy it into your book and annotate it so that you have notes on each step, outlining why the process is done and how it is achieved. Include as much detail as you can from the video for each stage of the process.**
3. **Compare and contrast** the fractional distillation of air to the fractional distillation of crude oil (Chapter 5).
4. **Describe** how the pure gases can be distributed.
5. Carry out some research to **identify** some of the main uses of oxygen, nitrogen and argon gas. Where relevant, **outline** the property that is linked to the particular use.
6. The fractional distillation of air is a very energy intensive process. **Suggest** what some of the environmental and economic consequences could be.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding and Criterion D: Reflecting on the impacts of science.

Figure 10.33 Flow diagram for the separation of air

Refer to the activities *Reactive metals* and *Acidic spices* in *MYP Sciences by Concept 2:* Chapter 2 for practical activities that determine the order of the reactivity of metals through their reactions with water, acids and in displacement reactions.

The order of the reactivity of metals is shown in the reactivity series in Figure 10.34a. This list is not exhaustive, but includes some of the most common metals that you will come across. A mnemonic is shown in the right-hand column, as a way to help you remember the order of the metals.

You may have noticed that the elements carbon and hydrogen are not metals. So why are they often also included in the reactivity series? Can you suggest the reason hydrogen is included in the reactivity series (we mentioned this in Chapter 8)? The reason carbon is included will be explored later on in this chapter.

In Chapter 4, we saw that metals want to lose their outer shell electrons in order to obtain more stable, full electron arrangements. In Chapter 3, we explained that the ease with which the electrons are lost is what affects the reactivity of the metals. For this reason we see a specific pattern emerging that can be explained by making reference to the electronic configurations of the elements.

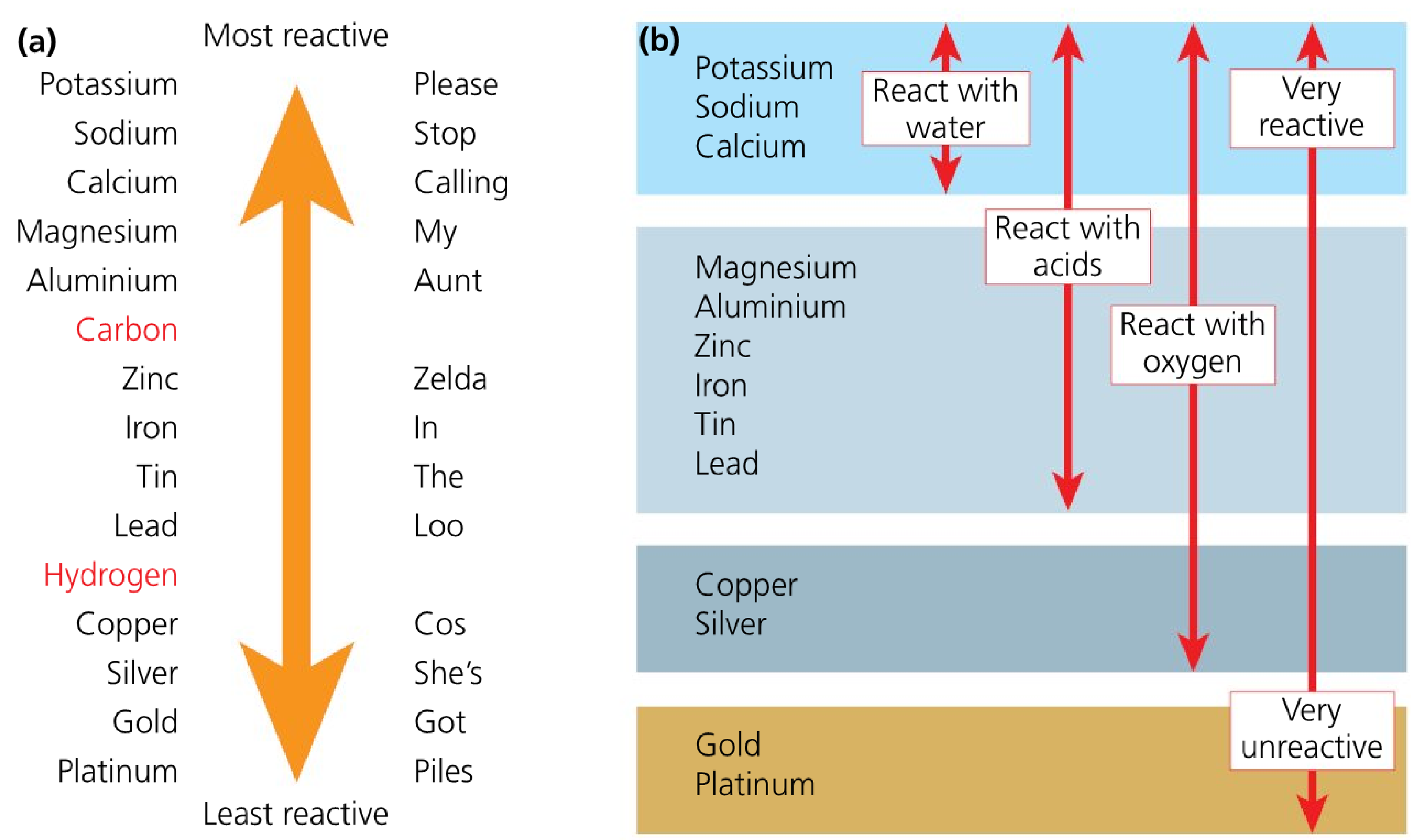


Figure 10.34 (a) The reactivity series; (b) the degree of reaction of a metal with water, acid and oxygen gives an indication of the reactivity of the metal

ACTIVITY: Determining metal reactivity using voltage

■ ATL

- Information literacy skills: Present information in a variety of formats and platforms; Process data and report results
- Critical-thinking skills: Interpret data; Draw reasonable conclusions and generalizations; Revise understanding based on new information and evidence

When metals give away their electrons they do so with a particular force; the greater the force, the more easily the electrons are pushed away. As a result, metal reactivity can also be determined by connecting two different metals together through a voltmeter and placing them in an electrolyte solution, thus creating a cell (see Chapter 8). The electrons will travel from the metal that wants to lose its electrons the most to the metal that least wants to lose them. The voltmeter measures the potential difference that causes the electric force on the electrons being pushed away. The bigger the voltage, the further away from each other the metals are in the reactivity series.

Figure 10.35 shows the equipment set-up of the experiment that a group of students carried out. Each time, a different metal was paired with copper metal for comparison.

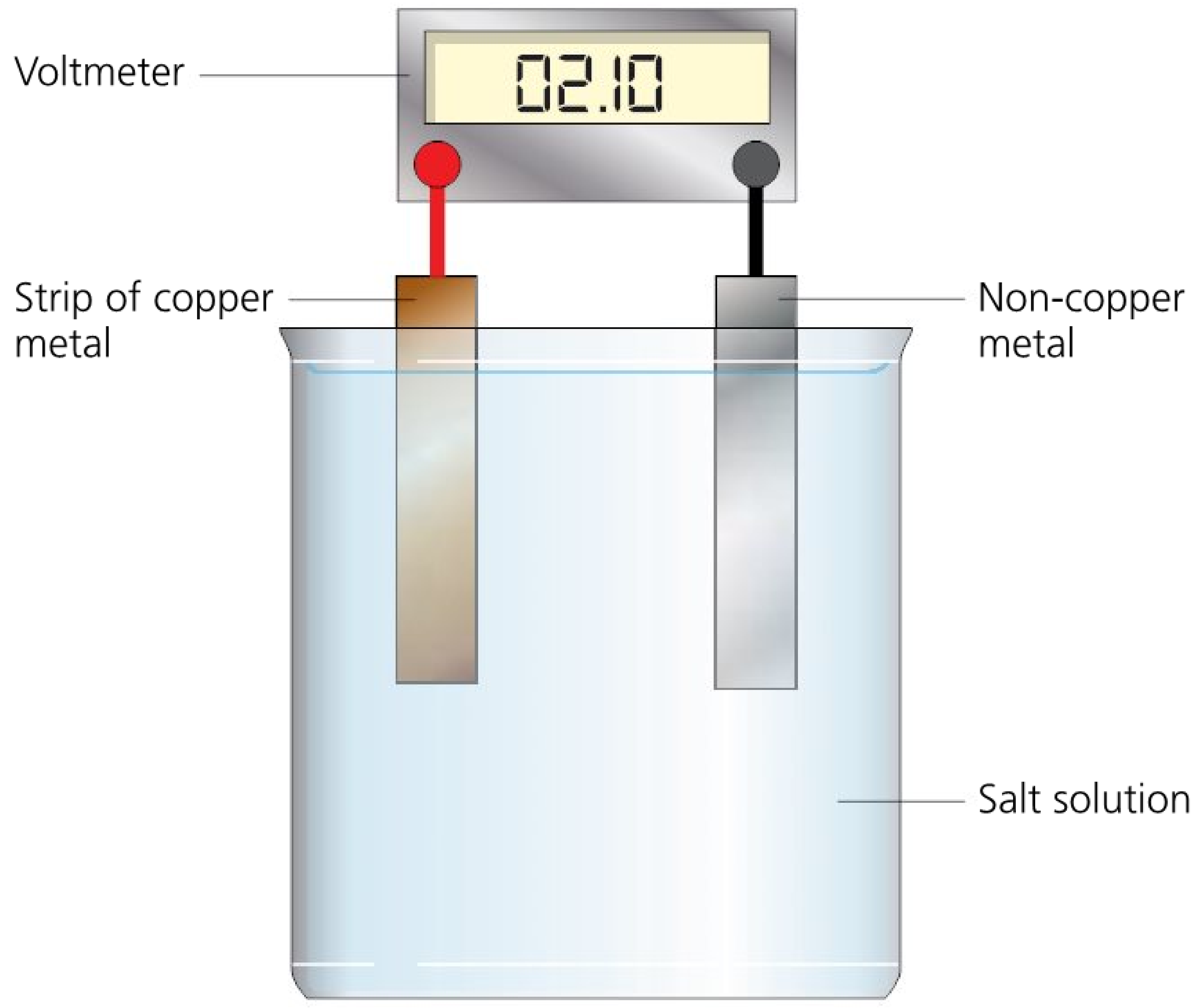
Use this information to answer the following questions.

1 **Some students have carried out this experiment but the data that they collected were recorded completely randomly in their exercise books. Organize the data into an appropriate table, carrying out any necessary processing. Then transform these data into a graph, showing any calculations you carry out.**

Student data:

Metal A: 0.72	Metal A: 0.73	Metal A: 0.77
Metal B: 0.93	Metal B: 0.88	Metal B: 0.98
Metal C: 0.21	Metal C: 0.23	Metal C: 0.55

2 **Deduce the order of the reactivity of the metals, explaining how you came to this conclusion.**



■ **Figure 10.35** Determining the reactivity of metals using voltage

The three metals used by the students were: magnesium, aluminium and beryllium. **Identify** which letter represents which metal and then **explain** the order, using your scientific knowledge about the factors that affect the reactivity of a metal.

3 **The students' original hypothesis was 'The copper–metal pair with the greatest voltage will be the metal with the greatest reactivity. As beryllium is in group 2, it will be the most reactive and therefore show the highest voltage'. Evaluate the validity of the hypothesis, based on the investigation outcome.**

4 **The investigation was carried out in two lessons, over two different days. The students admitted that they did not always control their control variables as well as they should have and that these two factors may have had an effect on their results. Evaluate the method.**

5 **Describe improvements and extensions to the investigation, explaining how the investigation would benefit from these.**

◆ Assessment opportunities

- This activity can be assessed using Criterion C: Processing and evaluating.

Metals below copper in the reactivity series are native metals which means that they can simply be separated from the surrounding rock.

The metal copper and those above it in the series are found as compounds. The compound is usually the metal oxide (as the element is exposed to the air) but can also be the metal sulfide. Elements below carbon in the reactivity series are less reactive than carbon. That means that if the metal compound is reacted with carbon, the more reactive carbon will displace the metal. For example:

zinc oxide + carbon → zinc + carbon monoxide

However, if the metal is more reactive than carbon, i.e. above carbon in the reactivity series, carbon is not capable of separating the metal out. A more energy intensive process is needed to separate the stronger bond and this is achieved through electrolysis.

ACTIVITY: Extracting aluminium by electrolysis

ATL

- Transfer skills: Apply skills and knowledge in unfamiliar situations; Make connections between subject groups and disciplines; Transfer current knowledge to learning of new technologies
- Communication skills: Take effective notes in class; Make effective summary notes for studying

In Chapter 8 we learnt about the electrolysis of ionic compounds, in the molten and aqueous state. A metal oxide is an example of an ionic compound, and a reactive metal can be separated from its compound by passing an electric current through it. In this activity, you will find out about the extraction of another extremely important metal, aluminium (called aluminum in the USA).

This video explains how aluminium is extracted from aluminium oxide by the process of electrolysis:
www.youtube.com/watch?v=mvDHeYI-a00

Watch the video and use it to help you answer the questions below.

1 **State some of the products that aluminium is used in and some of the properties that make aluminium so important.**
2 **Aluminium is extracted from a white powder, alumina. Outline where alumina comes from and what it is.**
3 **Sketch an electrolysis cell.**
4 **Explain why aluminium oxide is in the molten state.**
5 **Outline why the aluminium oxide is dissolved in molten cryolite.**
6 **Outline what the anode and cathode are made of.**
7 **Describe what happens to the aluminium and oxide ions during the electrolysis process.**
8 **Formulate half-equations for each reaction.**
9 **Explain why the positive electrode (anode) needs replacing often.**
10 **Discuss and evaluate the extraction of aluminium, making reference to economic, environmental and social world factors.**

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding and Criterion D: Reflecting on the impacts of science.

ACTIVITY: Extracting metals by reduction by carbon

ATL

Critical-thinking skills: Practise observing carefully in order to recognize problems; Interpret data

Materials and equipment (per group)

- Heatproof mat
- Tripod
- Bunsen burner
- Pipe clay triangle
- Crucible and lid
- Tongs
- Spatula
- 100 cm^3 beaker
- Powdered charcoal
- Samples of copper (II) oxide, lead (II) oxide, iron (III) oxide
- Sticky notes

Safety: Safety goggles should be worn at all times. Students should carry out the experiment standing. The experiment should take place in a well-ventilated room; should anyone be pregnant or breastfeeding it is advised that the experiment with lead (II) oxide be excluded. Lead (II) oxide and copper (II) oxide are harmful if swallowed and inhaled while copper (II) oxide can also cause skin irritation. Most of the substances are in the form of a fine powder so care must be taken when handling them. Students should practise lifting the lid of the crucible and moving the crucible before starting the experiment and should be warned to take extra care not to touch any of the equipment which will be hot.

Method

1. Set up the equipment as in Figure 10.36.
2. **Select** one of the metal oxides and place an equal amount of it and the charcoal in the beaker, mixing the substances well.
3. Pour the contents into the crucible, before covering them with a layer of charcoal.
4. Cover the crucible with the lid and begin to heat the mixture strongly for about 5 minutes.
5. Turn off the Bunsen burner and allow the mixture to cool down. Do not touch any of the equipment, which will all be very hot. While you are waiting, answer Question 1 in the Analysis section.
6. Use the tongs to remove the crucible lid and tip the contents of the crucible onto the heatproof mat, observing any changes.

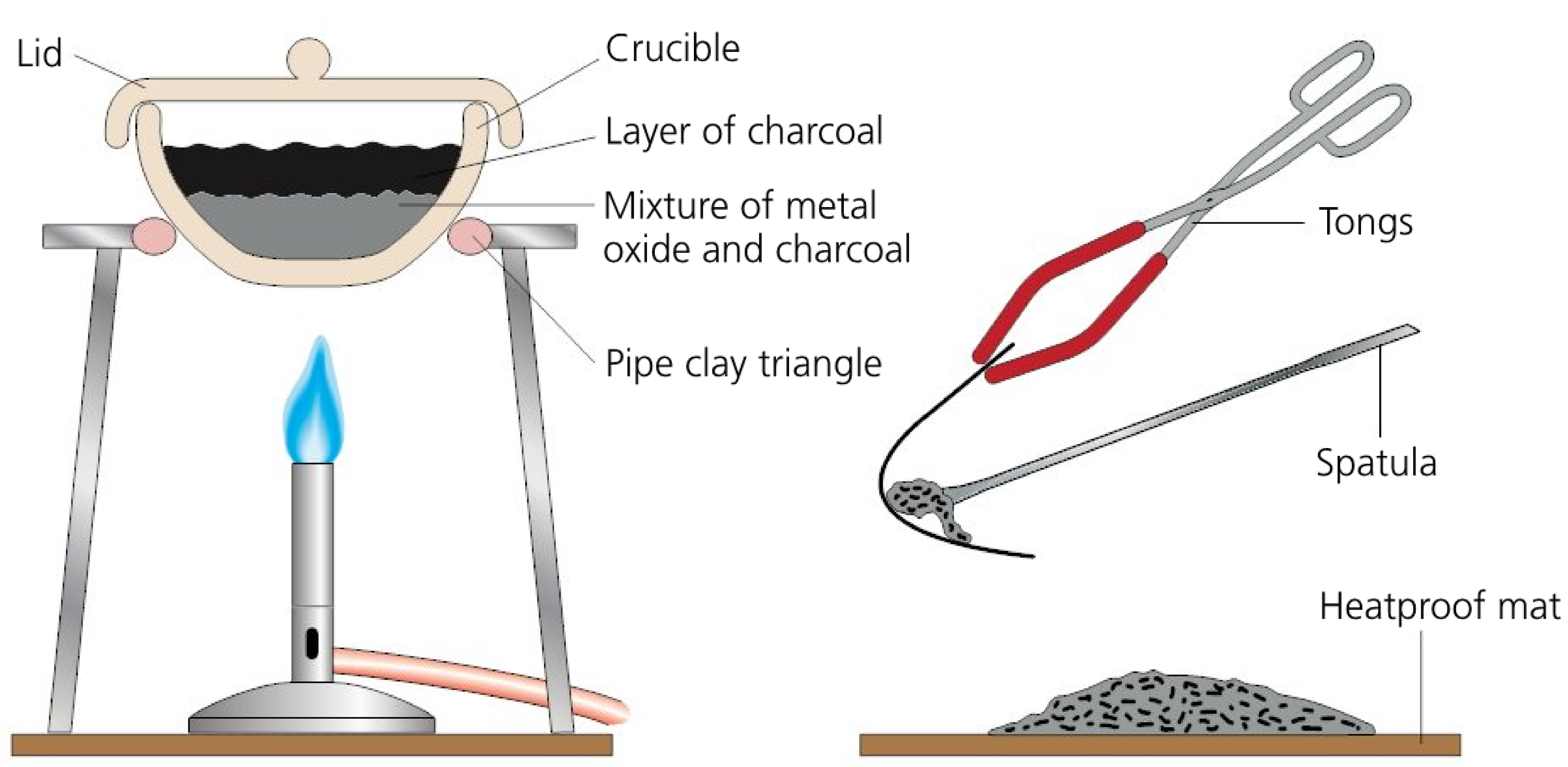


Figure 10.36 The experimental set-up for the reduction by carbon experiment

Analysis

1. **Predict** what will happen in the reaction of all three metal oxides with charcoal (carbon), by writing word equations for each.
2. **Describe** observations for the reaction of the metal oxide you used, making sure you clearly state which metal oxide was used.
3. **Formulate** a balanced symbol equation with state symbols for the reaction that you carried out.
4. **Write** the name of the metal oxide you used on a sticky note and place it next to your heatproof mat. **Find** the results of the metal oxides you did not test, **describing** both the initial colour of the metal oxide and the product on the heatproof mat in your notes.
5. **Suggest** why it was important to wait until the reaction was completed and the equipment cooled before removing the crucible lid.
6. **Explain**, making reference to one of the definitions of reduction in Chapter 8, why this method is called reduction by carbon.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.

ACTIVITY: Is it worth it? The extraction of iron using a blast furnace

ATL

- Critical-thinking skills: Evaluate evidence and arguments; Gather and organize relevant information to formulate an argument; Identify obstacles and challenges
- Communication skills: Read critically and for comprehension; Make inferences and draw conclusions; Use and interpret a range of discipline-specific terms and symbols

You were introduced to the extraction of iron by the blast furnace in *MYP Sciences by Concept 2:* Chapter 2. In this activity you will build on this information, in order to evaluate this method of extracting iron.

The following videos can be starting points:

www.youtube.com/watch?v=fxBIgbRT8fw&list=PLcvEcrsF_9zI8oZvkzZt0K_uxXJcQWI5T&index=4

www.youtube.com/watch?v=9l7JqonyoKA

Find more information by searching: **uses of iron** and **steel production and environmental impact**.

1. **Describe** the specific issue (problem) that the blast furnace solves.
2. **Explain** the science behind the blast furnace. **Formulate** correct word equations and balanced symbol equations with state symbols for the following reactions:
   a. the reaction of iron (III) oxide with carbon monoxide to iron and carbon dioxide
   b. the thermal decomposition of calcium carbonate
   c. the formation of slag, calcium silicate ($CaSiO_3$), from solid calcium oxide with solid silicon dioxide (silica or sand – impurities in the haematite).
3. **Deduce** which substance has been reduced and which has been oxidized.
4. **Evaluate** the extraction of iron in this way with reference to social, economic, political or environmental factors.

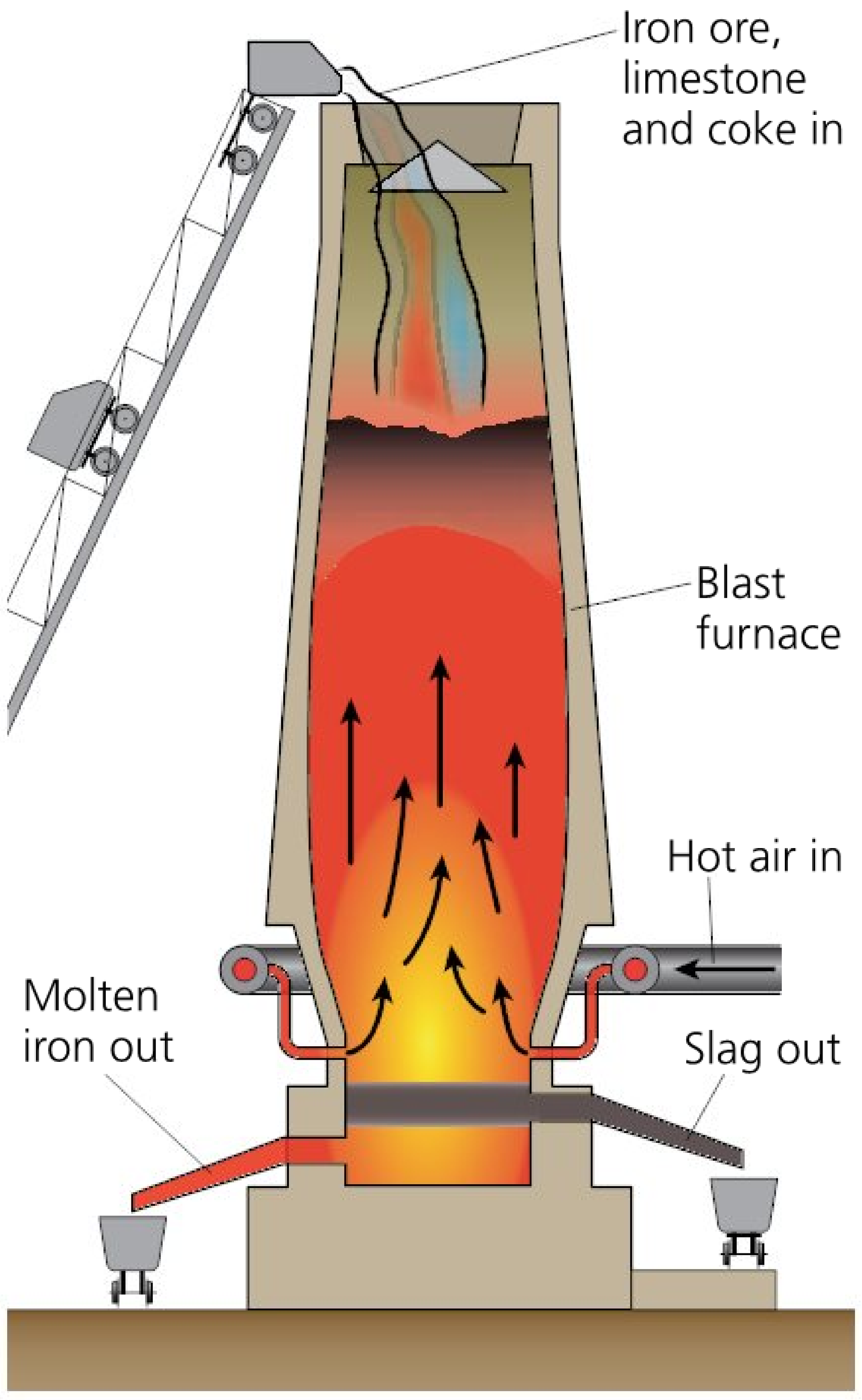


Figure 10.37 A blast furnace is used to extract iron from its ore

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion D: Reflecting on the impacts of science.

WHAT FACTORS CAN AFFECT THE RATE OF A REACTION?

In *MYP Sciences by Concept 2:* Chapter 2 we looked at the oxidation of iron (rusting). This is an example of a slow reaction but there are a number of factors that can affect how fast chemical reactions occur. This is significant not only for the corrosion of metals, but also in industrial processes that make chemical products. In a world driven by money, faster is always going to be better.

The **rate** of a reaction is defined as the change in the concentration of the reactants or products of a chemical reaction over a certain period of time. The rate of a reaction, cannot, therefore, be measured directly, but is determined from a graph.

Links to: Mathematics

In mathematics, how do you measure the rate of change of a factor, for example on a graph?

THINK–PAIR–SHARE

Using your scientific knowledge, and considering what you learnt in Chapter 5 about the factors that affect reactions of enzymes, **suggest** some factors that you believe will affect the rate of chemical reactions.

Compare these to those of your learning partner. Now **discuss** what things you could measure in order to **determine** the rate of a chemical reaction. **Share** all your points as a class.

Hint

Reactants could be solids; products could be gases.

The main factors that affect the rates of chemical reactions are concentration (when dealing with solutions), surface area (when dealing with solids), temperature and the presence of a catalyst. Light can also affect the rate of some chemical reactions.

DISCUSS

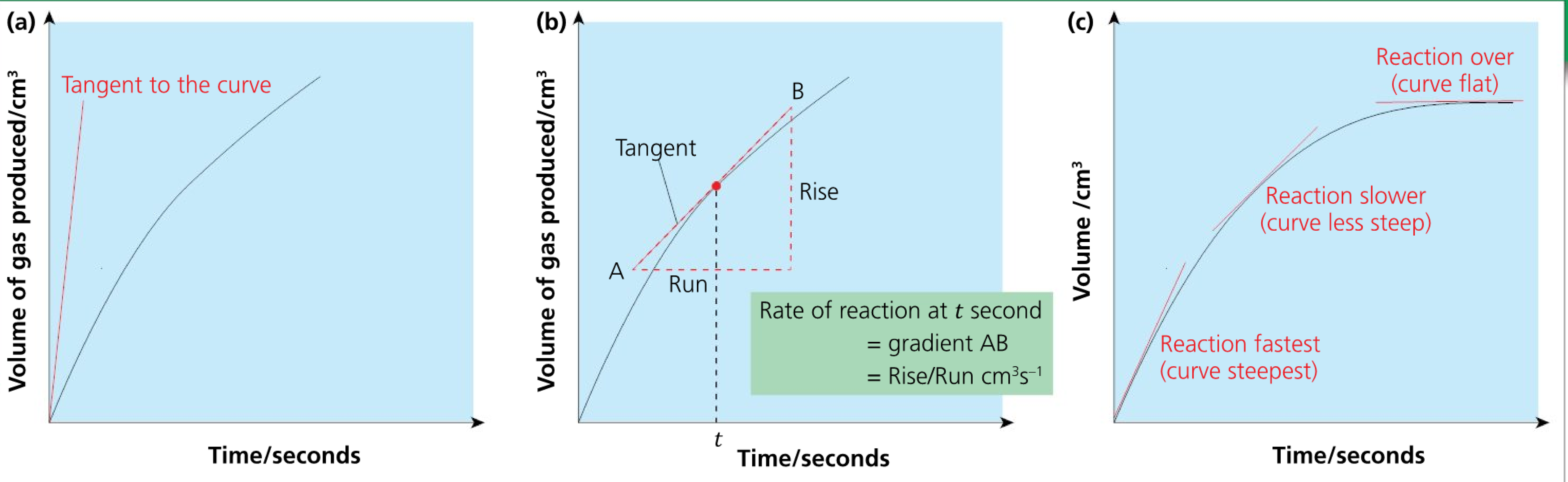
What very important biological process does light affect? What happens when light is absent?

The change in the concentration of the reactants or products can be measured by monitoring a property that will change as the reaction progresses, i.e. as the reactants change into products. Depending on the chemical reaction taking place, and the physical states of the reactants and products, the following can be monitored and then used to determine the rate of a chemical reaction:

- If one of the reactants is a solid and one of the products is a gas, the change in the total mass of the reactants can be measured over time (loss of reactant). In an open system, the gas will escape. According to the law of conservation of mass, the total mass of the reactants must be equal to the total mass of the products, so if the gas escapes, any mass change will be due to the loss of the product.
- If one of the products is a gas, the volume of gas produced (volume of product) can be measured over time.
- If the chemical reaction involves acids and bases, the change in pH over time can be measured.
- If the chemical reaction involves a change in colour, the time for a change in colour to occur can be measured.

The rate of a reaction can be determined from the graph of the experimental results. The rate of change can be determined by measuring the gradient of a line of best fit called the tangent on the graph (see Chapter 2). The rate of a reaction can be expressed in three ways:

- the initial rate of the reaction; this is determined by measuring the gradient of a tangent at $t = 0$
- the rate at time t; this is determined by measuring the gradient of a tangent at time = t
- the average rate of the reaction; this is determined by calculating the total change in the property measured and dividing by the time it took for that change to occur.



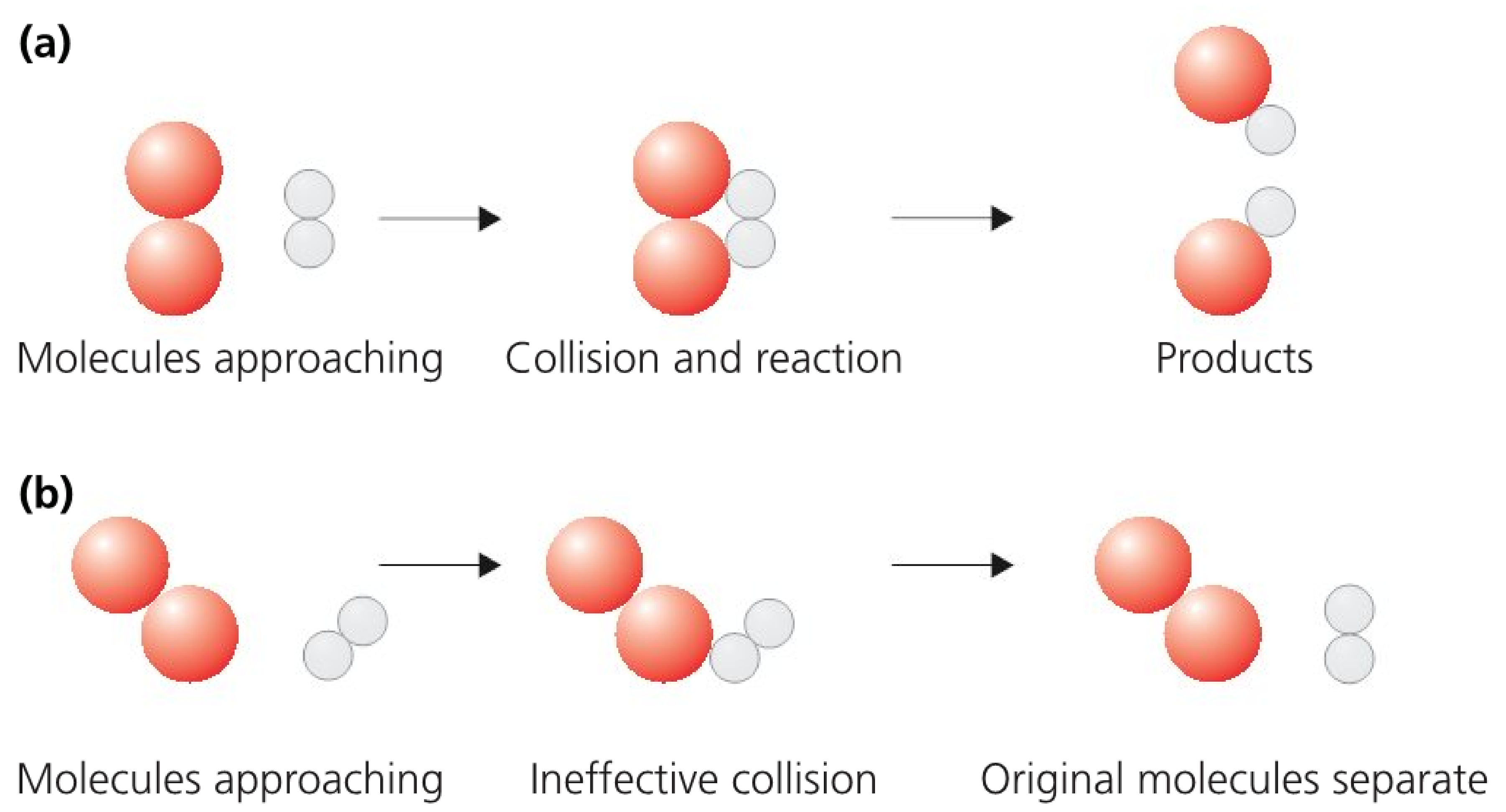
■ **Figure 10.38** By measuring the gradient of the tangent, the rate of a reaction can be determined. The tangent in (a) determines the initial rate of the reaction and in (b) determines the instantaneous rate at time, *t*. The steeper the tangent, the faster the rate of the reaction which decreases as the reaction progresses (c).

So how do temperature, concentration, surface area and the presence of a catalyst affect the rate of a reaction? It all comes down to **collision theory**. Collision theory states that in order for a chemical reaction to occur, three things must happen:

- There must be physical contact between the particles, i.e. they must collide.
- The particles must collide with the correct orientation.
- The particles must collide with the minimum amount of energy that is required to start the reaction, which is the amount of energy needed to break the bonds, called the **activation energy (E_a)**.

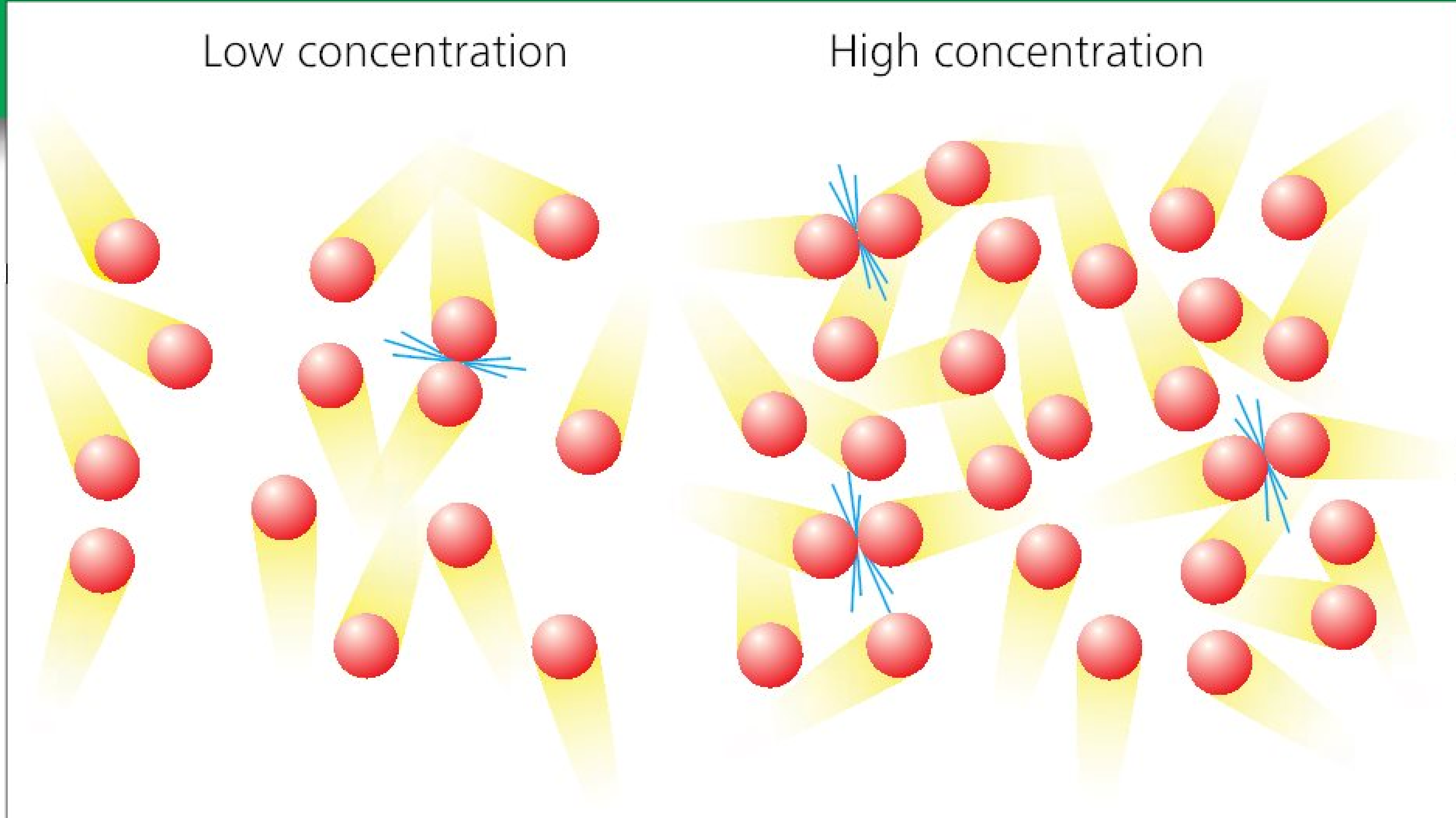
DISCUSS

Where have you met the term 'activation energy' before? Was the context the same?



■ **Figure 10.39** (a) If the approaching molecules collide with the correct orientation and enough kinetic energy to break the bonds of the reactants (activation energy), products will be formed. (b) If the approaching molecules do not collide with the correct orientation, or do not have enough kinetic energy to break the bonds of the reactants (activation energy), the reactants will bounce off each other and no products will be formed.

> **EXTENSION: GOING FURTHER**
>
> **Calculate** the total surface area available for reaction in the three examples provided.



■ **Figure 10.40** Collision theory and the effect of concentration (or pressure)

Concentration

An increase in the concentration of a solution means that there are more of the reacting particles in a given volume, essentially bringing the particles closer together. The closer the particles are, the greater the probability of a collision, therefore the greater the frequency of successful collisions and the faster the rate of the reaction (Figure 10.40).

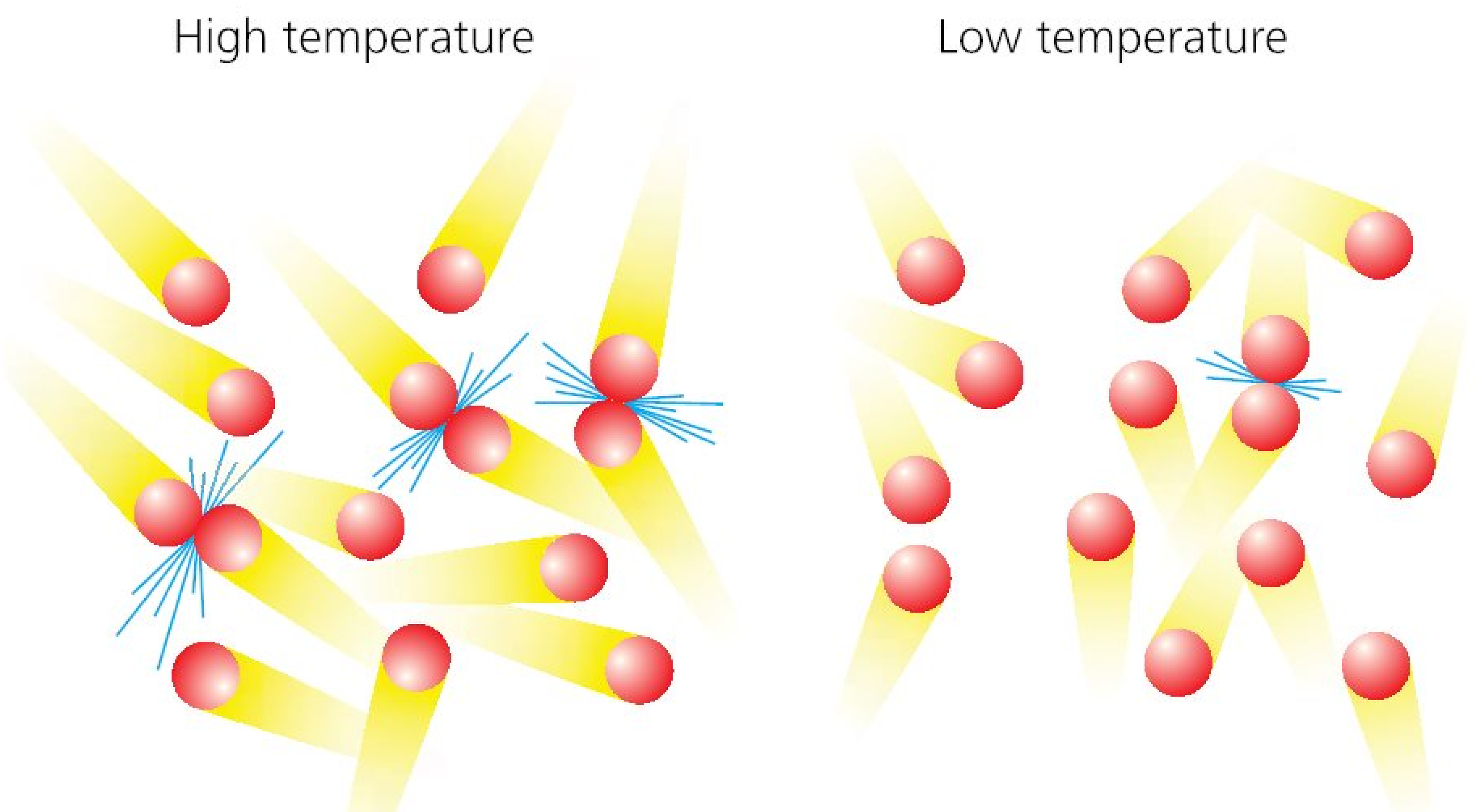
Concentration tends to refer to solutions. But the effect of increasing the concentration of a solution is the same as increasing the pressure of a gas; at a higher pressure, the gas particles are pushed closer together in a given volume.

Surface area

When a chemical reaction involves a reactant that is in the solid state, the reaction will occur on the surface of the solid. The smaller the pieces a given mass of solid is broken down into, the larger the surface area and therefore the more particles available for reaction (Figure 10.41). This increases the frequency of successful collisions.

Temperature

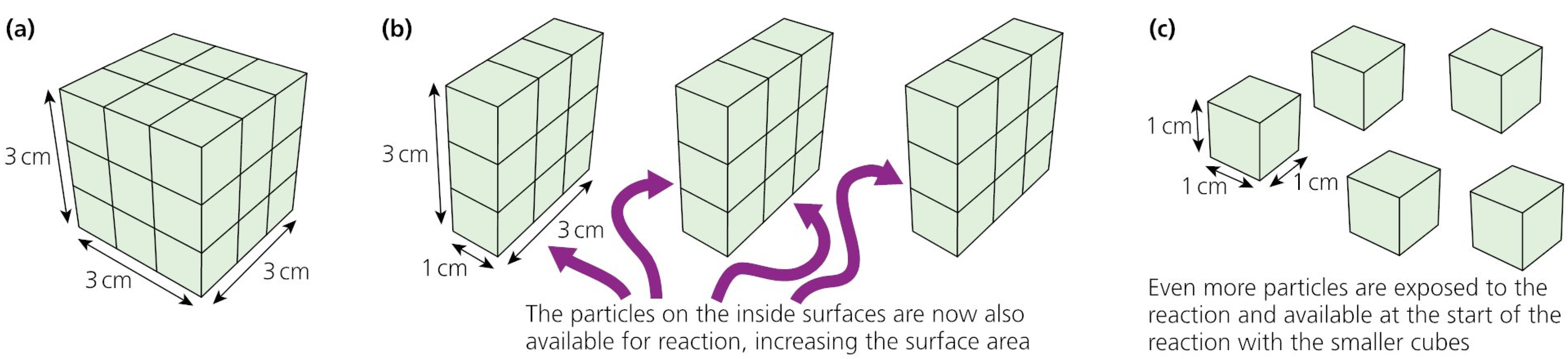
In Chapter 5, we saw that the temperature of the particles in a system is the average kinetic energy of the particles. The faster particles travel, the greater the probability of a collision, therefore the greater the frequency of successful collisions and the faster the rate of the reaction (imagine all of your class members walking around your classroom slowly and then everyone running around the same space).



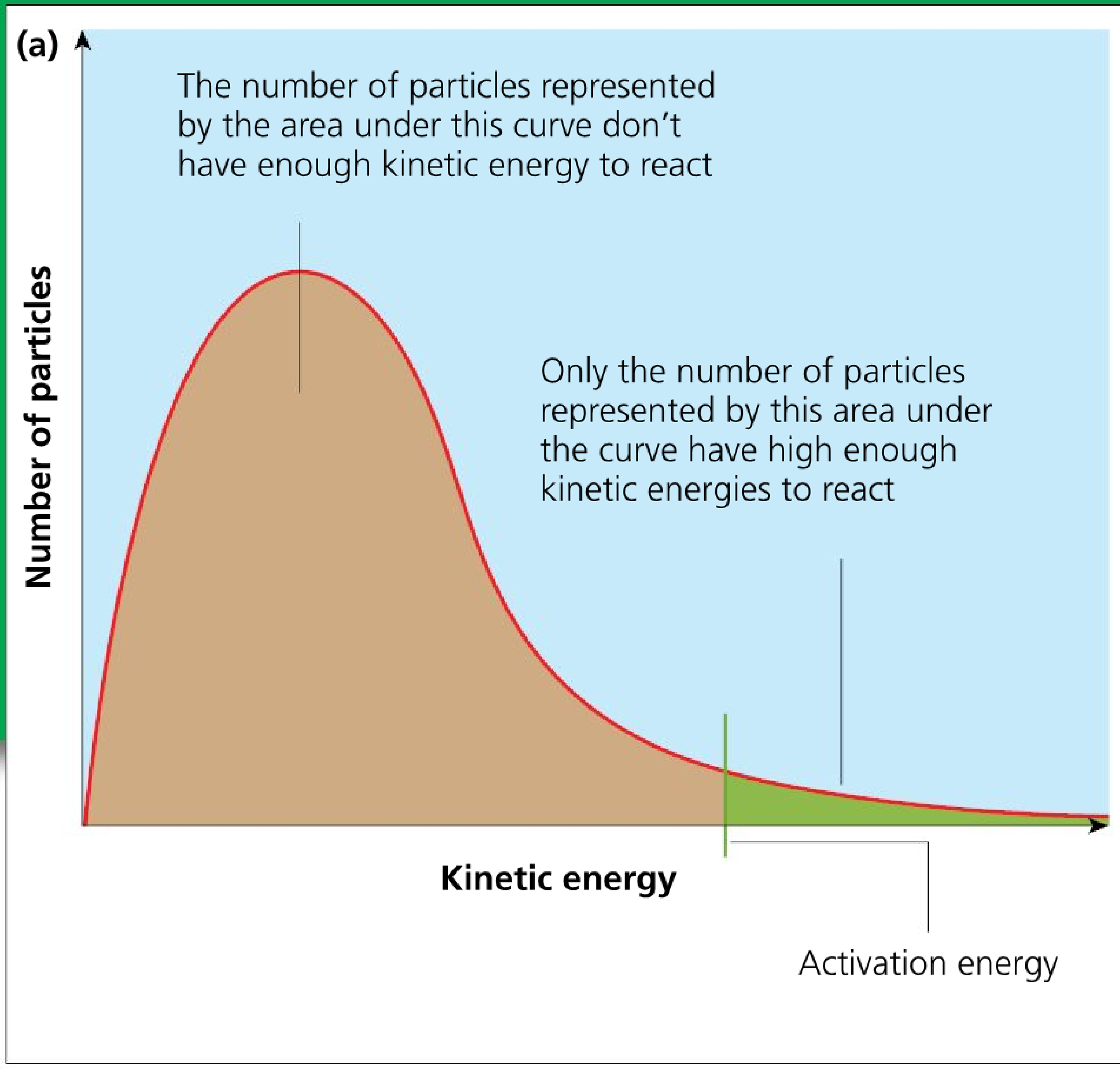
■ **Figure 10.42** Collision theory and the effect of temperature

However, increasing the temperature increases the rate of the reaction for an additional, and more significant, reason; it means more particles now have the minimum amount of energy needed to react (the activation energy). This means that there is a greater probability of collisions resulting in a reaction. A 10 °C increase in temperature approximately doubles the rate of a chemical reaction.

In a given sample of gas, all of the particles will not have the same kinetic energies, but will have a range of energies.



■ **Figure 10.41** (a) An imaginary 3 cm × 3 cm × 3 cm cube has the smallest surface area. (b) Slicing the cube into three 1 cm × 3 cm × 3 cm pieces increases the surface area by exposing the inner surfaces, but not as much as breaking it into (c) 27 1 cm × 1 cm × 1 cm cubes.



■ **Figure 10.43** (a) Showing the activation energy (E_a) on the distribution curve indicates the number of particles that have the minimum amount of energy needed (in green). (b) Increasing the temperature results in more particles having the required activation energy.

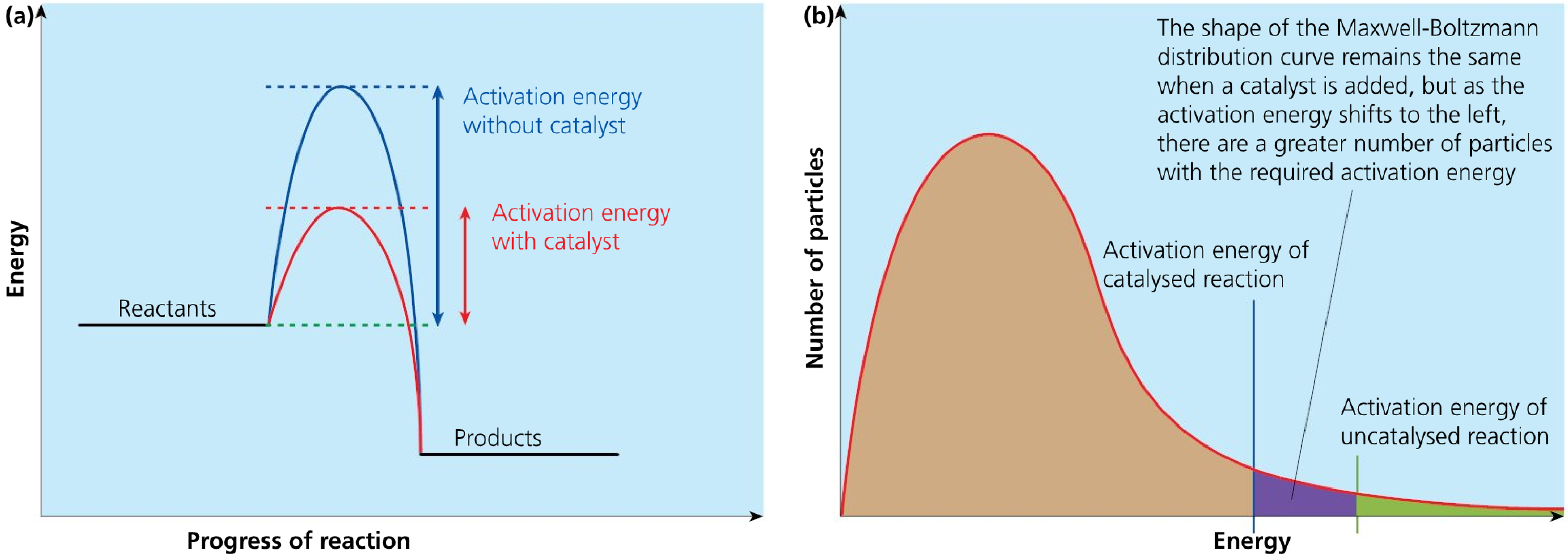
The Maxwell–Boltzmann distribution curve shows the distribution of the kinetic energies of the molecules of an ideal gas and how these can vary. The area underneath the graph represents the total number of particles in the system.

Marking the activation energy (E_a) on the Maxwell–Boltzmann distribution curve shows the number of particles that have the minimum amount of energy needed for a successful reaction to occur. These are shown under the curve and to the right of the activation energy in green. Increasing the temperature causes a change in the shape of the distribution; while the activation energy remains the same, the area under the curve is now greater, representing a larger number of particles that have the minimum amount of energy needed for a successful reaction (Figure 10.43).

Catalyst

In Chapter 5, we saw how biological substances called enzymes are capable of speeding up reactions in a cell. In a chemical reaction, a **catalyst** behaves in the same way; it is a substance that speeds up a chemical reaction but without actually taking part in the reaction.

A catalyst speeds up a chemical reaction by providing an alternative pathway that has a lower activation energy. The result is that there are a greater proportion of particles that have the minimum amount of energy needed to react, therefore a greater frequency of successful collisions. This can be shown in both an energy level diagram (Figure 10.44a) and a Maxwell–Boltzmann distribution curve (Figure 10.44b).



■ **Figure 10.44** (a) The effect of a catalyst shown on the energy profile diagram of a reaction. (b) Adding a catalyst results in there being a greater number of particles with the required activation energy.

ACTIVITY: Investigating rates of reaction

ATL

- Organization skills: Plan short- and long-term assignments; Meet deadlines; Use appropriate strategies for organizing complex information
- Information literacy skills: Collect, record and verify data; Present information in a variety of formats and platforms; Process data and report results
- Critical-thinking skills: Interpret data; Evaluate evidence and arguments; Test generalizations and conclusions
- Creative-thinking skills: Make guesses, ask 'what if' questions and generate testable hypotheses; Apply existing knowledge to generate new ideas, products or processes

Your task is to **design** and carry out an experiment to test one of the factors that can affect the rate of a reaction. In order to do this, you must choose between one of the following reactions:

- **calcium carbonate with dilute hydrochloric acid**
- **the decomposition of hydrogen peroxide, using manganese (IV) oxide as a catalyst**
- **sodium thiosulfate and dilute hydrochloric acid**
- **magnesium ribbon with dilute hydrochloric acid.**

Before you start, your teacher will demonstrate how you set up an experiment if you are measuring the change in mass or the change in volume. These set-ups are shown in Figure 10.45.

Refer to the MYP *Sciences Inquiry Cycle* in Chapter 1 and think what you have learnt about designing a safe and valid investigation.

You must decide on the amounts of substances and concentrations individually, and ensure you collect sufficient and relevant data.

Hint

Refer to Chapter 6 for how to create concentrations of different dilutions.

Safety: Make sure you share your plan with your teacher before you begin. They will ensure that your experiment is feasible and safe.

After you have collected your results, you must **organize**, transform and **present** your data, **interpret** your results and **explain** them using scientific reasoning. You should **evaluate** the validity of your hypothesis and method and **describe** any improvements to your method.

Assessment opportunities

- This activity can be assessed using Criterion B: Inquiring and designing and Criterion C: Processing and evaluating.

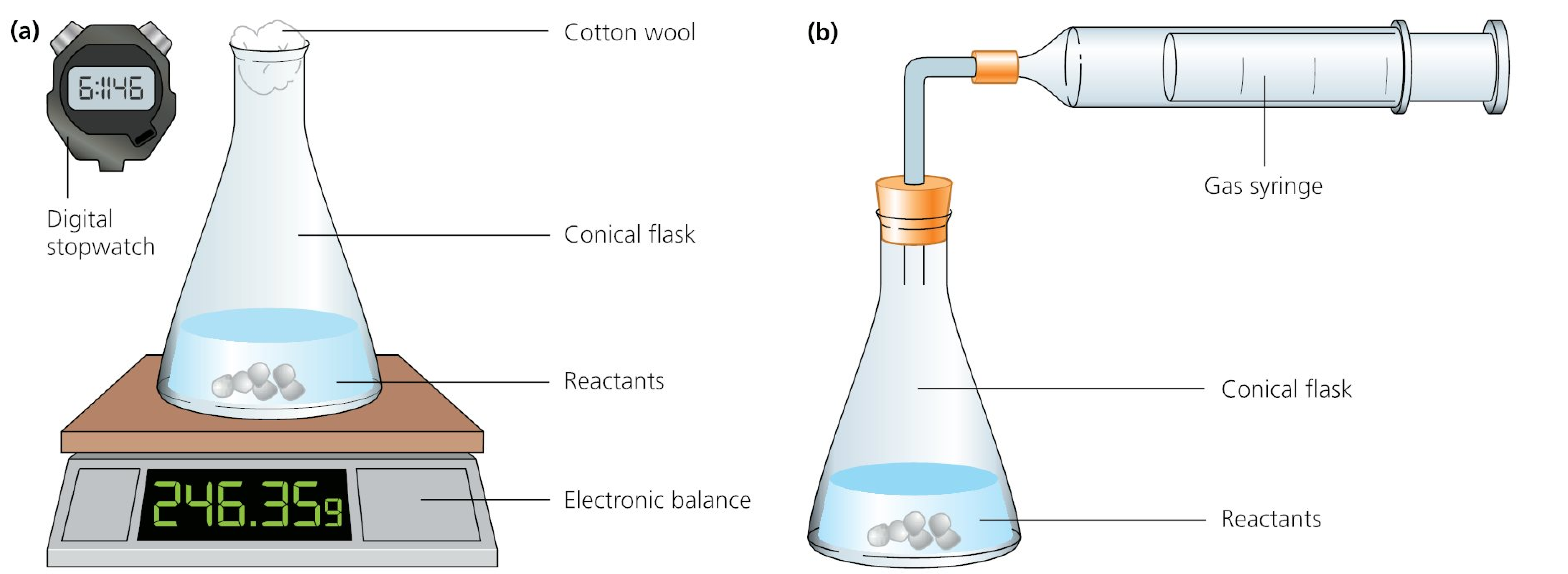


Figure 10.45 (a) Measuring the change in mass (due to the loss of a gaseous product); (b) measuring the change in volume (due to the formation of a gaseous product)

! Take action: Eyes in the sky

ATL

- Communication skills: Use a variety of media to communicate with a range of audiences
- Information literacy skills: Compare, contrast and draw connections among (multi)media resources

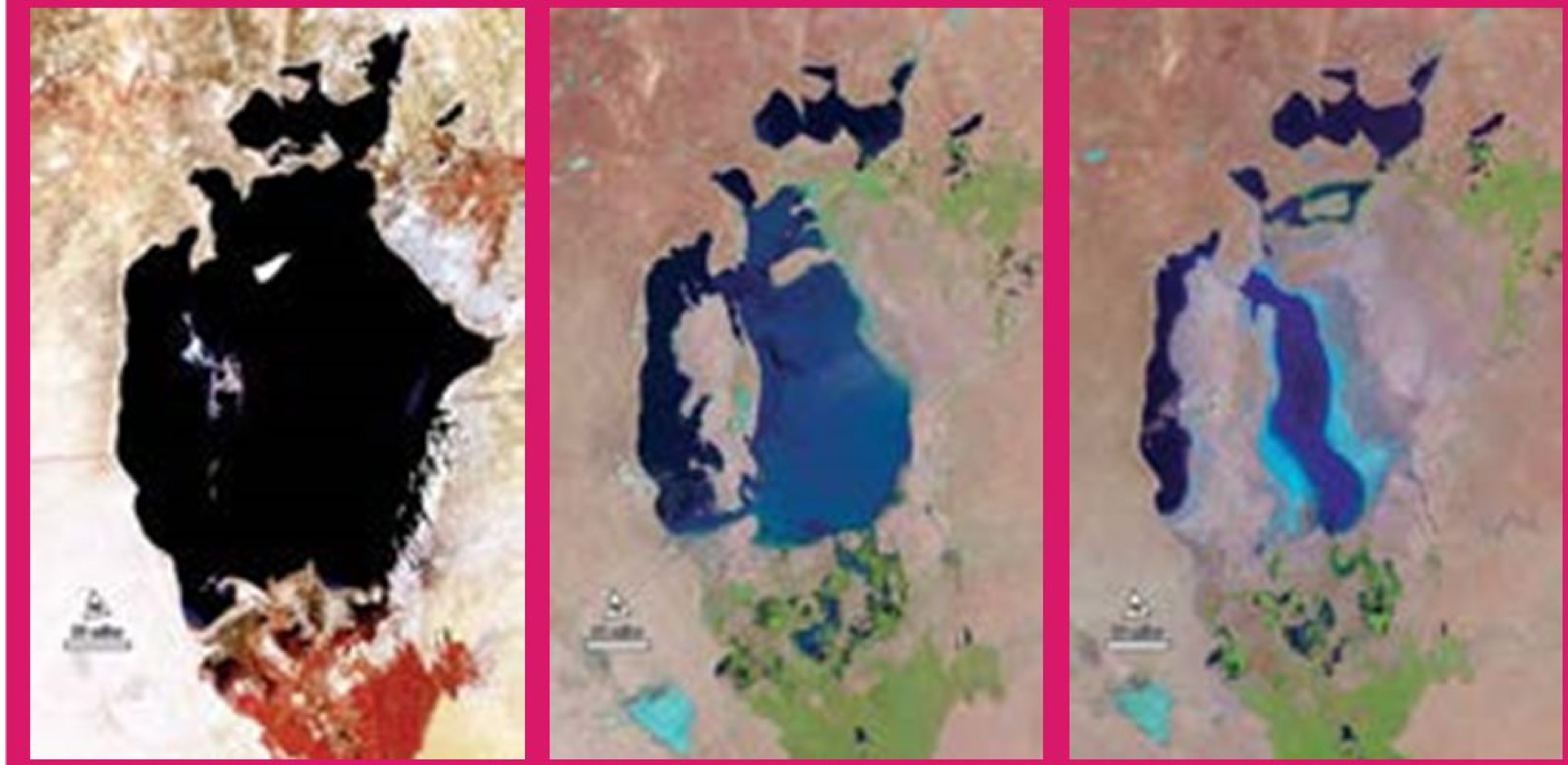
! In 1977 the Aral Sea lay across the borders of the Asian nations of Uzbekistan, Turkmenistan and Kazakhstan. Satellite images such as those in Figure 10.46 enable us to see the impact of human activity on this important inland sea.

! Find out what happened to the Aral Sea during this time period.

! Carry out research to find out about other environmental changes that have been revealed by satellite photography.

! Make copies of the images and use them to raise awareness of the growing influence of humanity on the Earth's different spheres:

! You could blow up the images and post them around your school, then use a school assembly to explain your actions. Make a website hosting the images and linking to information on each of the cases.



■ **Figure 10.46** The Aral Sea, photographed by satellite from 1977 to 2013 (image source: USGS/NASA)

SOME REVIEW PROBLEMS TO TRY

1 The radius of the Earth is 6400 km. A space station is in geostationary orbit at altitude 3200 km above the Earth's surface.

a If the force of gravity experienced by the space station on the Earth's surface is F, **calculate** the force of gravity experienced by the space station in orbit in terms of F.

b The astronauts on the space station feel as though they have no weight at all and 'float' inside the space station. **Explain** why this effect occurs.

c The space station fires its rockets for a short time to increase its speed in a direction tangential to the orbit, but remains in orbit around the Earth. **Describe** the effect of this increase on the orbit of the space station.

2 A piece of magnesium was added to a solution of copper (II) sulfate.

a **State** what type of reaction this is and why it would occur. **State** the name of the new salt formed.

b At some point, all of the magnesium is coated with an orange substance, at which point the reaction stops. **Outline** why.

c The reactivity of a metal determines the method that will be used to extract it. The following metals have been placed in order of reactivity, from the most to the least reactive. **Deduce** how the metals will be extracted, explaining the reasoning for your choice.

Li, Ca, Zn, Cd, Ni, Sn, Cu, Ag, Pd

d A student carried out an experiment to investigate what happened when she heated 10 g of four different metal carbonates in a test tube. She weighed out 10 g of each metal carbonate at the beginning of the experiment, heated it strongly with a Bunsen burner for 5 minutes and then weighed the solid left after heating. The results of her experiment are shown in Table 10.5.

Metal carbonate	Mass difference (initial mass – final mass)/g
zinc carbonate	1.9
calcium carbonate	0.7
copper (II) carbonate	3.5
sodium carbonate	0.0

■ **Table 10.5**

i **State** the type of reaction occurring. **Formulate** a balanced symbol equation with state symbols for the experiment with copper (II) carbonate and use your equation to **deduce** why the mass decreased during the experiment.

ii **Explain** the reason for a difference in mass change depending on the metal carbonate used in the reaction. **Predict** what would happen if all four were bubbled through lime water. **Suggest** how you could predict to what degree a metal carbonate will break down and **suggest** what would happen if magnesium carbonate was heated in the same way.

Reflection

In this chapter we have **described** some of the objects found in space and we have **described** the methods used by scientists to gather information about the Universe, including using optical instruments. We have **described** the interaction of different kinds of electromagnetic radiation with matter and **outlined** the function of the atmosphere and the Earth's electromagnetic fields in sustaining life. We have **described** the life cycle of stars and **outlined** how stars synthesize heavier elements that are recycled in the formation of planetary systems. We have **outlined** some of the evidence for an expanding Universe cosmological model and **reflected** on the way that cosmology affects our perspective of our own place in the Universe. We then focused on our Earth as a system of four spheres. We **outlined** the journey of our atmosphere from its original composition to the current composition and **explained** how the elements carbon and nitrogen move between the different spheres in the carbon and nitrogen cycles. We have **described** how we extract gases from the atmosphere and **outlined** their uses and **explained** how to extract metals from the lithosphere, evaluating the blast furnace in the extraction of iron specifically. We have **explained** how changes in concentration, surface area, temperature and the use of a catalyst can affect the rate of a chemical reaction.

<table>
<tr><th colspan="6">Use this table to reflect on your own learning in this chapter</th></tr>
<tr><td>Questions we asked</td><td>Answers we found</td><td colspan="4">Any further questions now?</td></tr>
<tr><td>Factual</td><td></td><td colspan="4"></td></tr>
<tr><td>Conceptual</td><td></td><td colspan="4"></td></tr>
<tr><td>Debatable</td><td></td><td colspan="4"></td></tr>
<tr><td rowspan="2">Approaches to learning you used in this chapter:</td><td rowspan="2">Description – what new skills did you learn?</td><td colspan="4">How well did you master the skills?</td></tr>
<tr><td>Novice</td><td>Learner</td><td>Practitioner</td><td>Expert</td></tr>
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<tr><td>Learner profile attribute(s)</td><td colspan="5">Reflect on the importance of being caring for your learning in this chapter</td></tr>
<tr><td>Caring</td><td colspan="5"></td></tr>
</table>

11 How do humans impact the environment?

In order to live **sustainable** lives, we need to learn from the **consequences** of our actions and **change** our relationship with the **environment**.

CONSIDER THESE QUESTIONS:

Factual: What impact has human activity had on our natural environment?

Conceptual: How can science help us understand complex natural systems?

Debatable: Should scientists be held accountable for how their discoveries are used?

Now **share and compare** your thoughts and ideas with your partner or with the whole class.

■ **Figure 11.1** Evidence that we are now living in the anthropocene?

IN THIS CHAPTER, WE WILL …

- **Find out** how human activity is affecting the ecosystems that surround us.
- **Explore** how science can provide solutions to problems, but sometimes can create new problems to be solved.
- **Take action** to engage with local environmental projects and to raise awareness of the dangers of carbon monoxide in the home.

These Approaches to Learning (ATL) skills will be useful …

- Information literacy skills
- Collaboration skills
- Critical-thinking skills
- Communication skills
- Transfer skills
- Creative-thinking skills

■ **Figure 11.2** Human activity is impacting the environment

◆ Assessment opportunities in this chapter:

The activities in this chapter will help you develop and evaluate your learning in these MYP Sciences learning objectives:

- ◆ **Criterion A:** Knowing and understanding
- ◆ **Criterion B:** Inquiring and designing
- ◆ **Criterion C:** Processing and evaluating
- ◆ **Criterion D**: Reflecting on the impacts of science

● We will reflect on this learner profile attribute …

- Principled – through evaluating research and the information we have, we will consider our position on issues.

KEY WORDS

climate	pyramid
fertilizer	responsibility
pollutant	web

In *MYP Sciences by Concept 1:* Chapter 6 and in the last chapter of this book you learnt about the different periods in the Earth's history. Although the Earth has changed throughout its history, for long periods of geological time the conditions on the planet have been characterized by particular kinds of process – for example, by volcanic activity or by cold surface temperatures. Earth scientists often describe such periods as geological eons, eras and periods. Some scientists now believe that human activity is changing the Earth's systems so profoundly that we ought now to consider ourselves as entering a new geological period: the **anthropocene**.

DISCUSS

The image in Figure 11.1 shows a mineral called simonkolleite. Read the following article to find out why this mineral might be a little unusual: www.newscientist.com/article/2122874-rock-solid-evidence-of-anthropocene-seen-in-208-minerals-we-made/

State when most minerals were formed and why were they formed then. **Describe** what the sources of these new human-made minerals are. **Evaluate** the suggestion to designate a new geological period.

How can science help us understand complex natural systems?

In Chapter 5, we focused on how organisms interact with their non-living environment to obtain what they need, using gas exchange as an example. All the non-living factors needed for survival – such as water, gases, minerals and sunlight – are called abiotic factors. In this chapter, we will look at how living things interact and obtain what they need from each other (biotic factors).

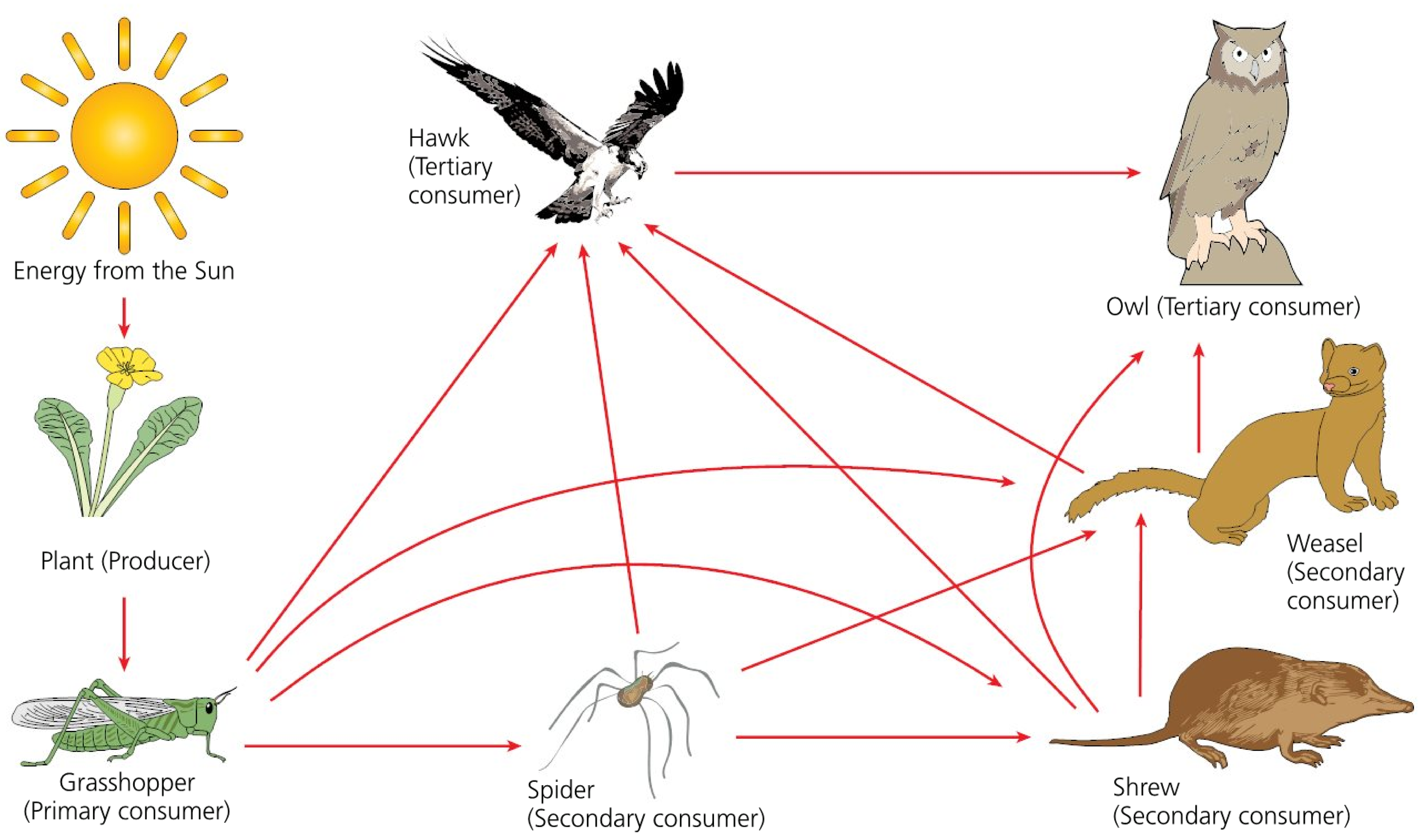
An ecosystem is a part of the environment where biotic and abiotic factors interact with each other. No living thing can exist independently of its environment: even plants that make their own food depend on insects for pollination. Living things interact with each other through feeding, breeding, to find shelter and so on, and their interdependency leads to a natural 'balance'.

FOOD CHAINS AND FOOD WEBS

Feeding relationships are the main interaction through which organisms obtain energy. Because plants do not rely on other organisms for feeding, they are called autotrophs and producers. Animals obtain energy by feeding on plants or other animals and are called heterotrophs and **consumers**. In a particular ecosystem, feeding relationships can be complex and are best represented by a **food web** (Figure 11.3). A **food chain** is a simplified part of a food web. Let us consider the food chain from the plant to the owl. One route to describe the feeding relationships can be written like this:

plant → grasshopper → spider → shrew → owl

Are there any other routes?



■ **Figure 11.3** An example of a forest food web

ACTIVITY: Who eats who?

ATL

- Communication skills: Use and interpret a range of discipline-specific terms and symbols; Organize and depict information logically

This activity will help you become familiar with some scientific terms and definitions used to describe relationships between organisms.

1 In pairs, carefully **observe** the feeding relationships shown in Figure 11.3. **Discuss** how to match the scientific terms to their definitions in Table 11.1. Make a copy of the table and in the third column, give an example when possible. (One example has been worked for you.)
2 **Identify** how many food chains are present in this food web and write them down starting from the producer to the top consumer.
3 With your partner, choose one organism to remove from the food web and **predict** the consequences on the ecosystem.

Scientific term	Definition	Example from the food web in Figure 11.3
trophic level	organisms that feed on producers	
food chain	organisms that feed on primary consumers	
producers	organisms that feed on secondary consumers	
consumers	the position an organism occupies in a food chain or a food web	
primary consumer	organisms that feed on other organisms and are unable to make their own food	
secondary consumer	a succession of organisms that eat another organism and are, in turn, eaten themselves	
tertiary consumer	organisms that use photosynthesis to make their own food	the green plant
omnivores	a feeding network made up of many different food chains	
herbivores	an animal that feeds on other animals	
carnivores	organisms that break down dead or decaying organisms	
decomposers	animals that feed on plants only	
food web	animals that feed on both plants and animals	

Table 11.1

QUANTIFYING FEEDING RELATIONSHIPS BETWEEN ORGANISMS

ACTIVITY: Spot the correct pyramid!

ATL

- Critical-thinking skills: Use models and simulations to explore complex systems and issues

Ecologists often use pyramids to show quantities and numbers of organisms in food chains and food webs.

There are three main types of pyramid:

1. ***pyramid of numbers*: represents the actual number of organisms in each trophic level**
2. ***pyramid of biomass*: represents the total mass of living things in each trophic level**
3. ***pyramid of energy*: represents how much energy is available in each trophic level.**

The following are three pyramids for the same food chain (a, b and c). In pairs, for each type of pyramid in Figure 11.4, **identify** which is a pyramid of numbers, biomass or energy.

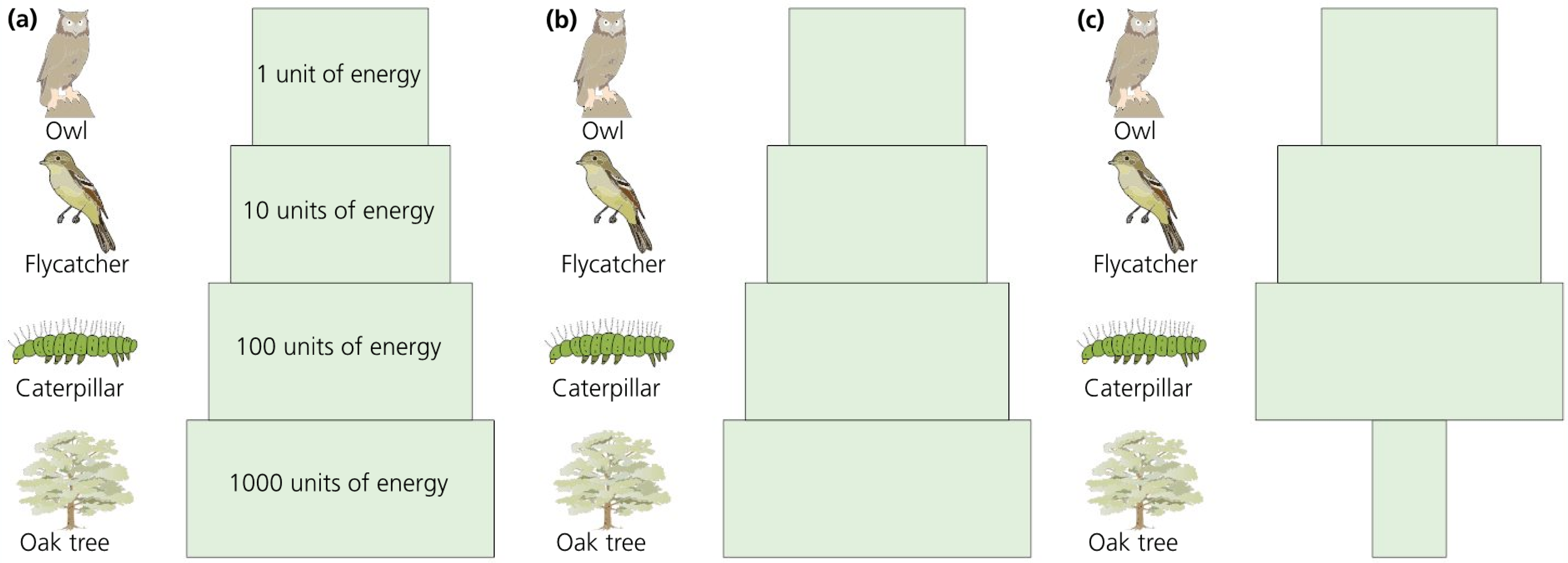
Justify your answer and **explain** how you reached your conclusion.

How would you represent a parasitic fungus that grows on the oak tree on each of these pyramids? **Explain** your answer.

What would the pyramids look like if the oak tree was replaced by the same number of tomato plants needed to feed the given number of caterpillars? **Justify** your answer with scientific reasoning.

◆ Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.



■ **Figure 11.4** The three types of ecological pyramids (a, b, c)

What impact has human activity had on our natural environment?

THINK–PAIR–SHARE

Think about the following questions and **write down** some key words and ideas. **Discuss** them in **pairs** and **construct** common answers between you. **Share** and exchange your thoughts and ideas in whole class discussions.

What do we mean by biodiversity? Is biodiversity good or bad for an ecosystem? Why? What is meant by species diversity? What is the relationship between biodiversity and the health of an ecosystem? What factors could affect biodiversity in a positive or negative way? How is biodiversity affected by changes to habitats?

ACTIVITY: What impacts?

ATL

- Information literacy skills: Access information to be informed and inform others; Make connections between various sources of information; Evaluate and select information sources and digital tools based on their appropriateness to specific tasks; Create references and citations, and construct a bibliography
- Communication skills: Collaborate with peers and experts using a variety of digital environments and media
- Critical-thinking skills: Gather and organize relevant information to formulate an argument; Evaluate evidence and arguments

In this activity you will collaborate with other students to carry out research and **evaluate** different ways in which humans impact ecosystems.

In groups, **evaluate** one of the issues in the blue box using a compass points routine.

Take a large piece of paper or an erasable whiteboard and mark out the points of the compass.

For North write down what you **N**eed to Know. For East write down what might be **E**xciting about this impact. For West write down what might be **W**orrisome about this impact. For South write down what might be your **S**uggestions for moving forwards.

At the end of the activity, put your compass charts on the walls of the classroom and review them all as a class.

deforestation	agriculture
industrialization	genetic modification
selective breeding, cross breeding and domestication of animals	fishing Are there any further issues you could add?

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion D: Reflecting on the impacts of science.

Of course humans also form a part of many ecosystems. In this section you will evaluate the human impact on ecosystems and our influences on their natural biodiversity.

Biodiversity is a concept you may have explored before, perhaps in *MYP Sciences by Concept Books 1* and *2*. The following activities will extend and enrich your knowledge and help you develop a critical perspective on the key issues.

ACTIVITY: Investigate the biodiversity in your area

ATL

- Information literacy skills: Collect, record and verify data
- Critical-thinking skills: Practise observing carefully in order to recognize problems

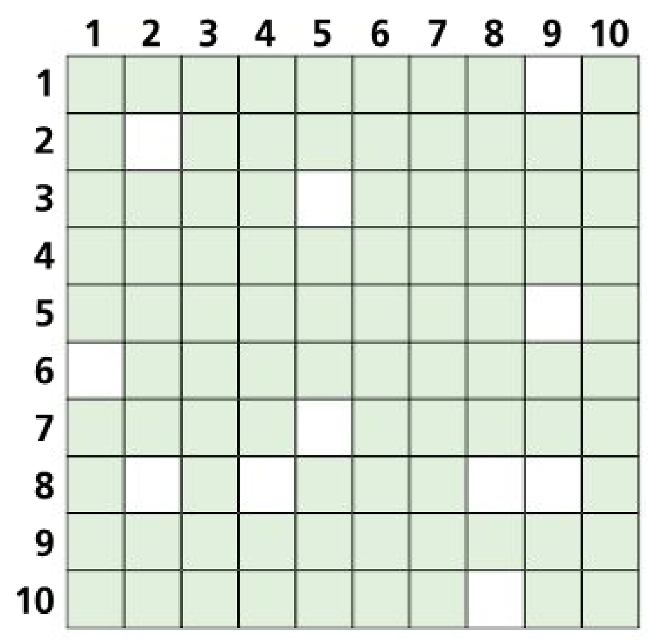
In this activity you will be an ecologist and you will **investigate** changes in biodiversity in your local area. You will plan and carry out an investigation and you will process and **analyse** your data.

- **First choose two areas of interest: one should be close to its natural state and another subject to impact by urbanization or human interference. Define your variables. What independent variable is changing between your sites? What dependent variable will you measure? You need to choose something that gives you an indication of the biodiversity of your areas of interest.**
- **Define your controlled variables. What must be kept the same between your chosen areas? Ecological studies often have uncontrolled variables; things you have no control of. Note these in your report.**
- **Find out about ecological sampling methods: quadrat sampling, transect sampling, counting insects in leaf litter.**
- **Design a safe method to assess the biodiversity of your area. Be pragmatic when working near hazards like rivers or lakes; only work in safe areas.**

Safety: Prepare a risk assessment as previously and show this to your teacher before beginning.

- **Collect and record any observations you make about habitats or different species you find.**
- **Ecological investigations may take a long time to complete, so if you find yourself not able to finish your work, make sure you think of the best ways to split the repeats of measurements in a way that doesn't affect your results.**
- **Organize, present, analyse and interpret the data. Consider any errors in the data and explain why this happened. This kind of biology experiment can have large variations between different samples.**
- **Evaluate your hypothesis and any errors in your method.**

(a) a quadrat

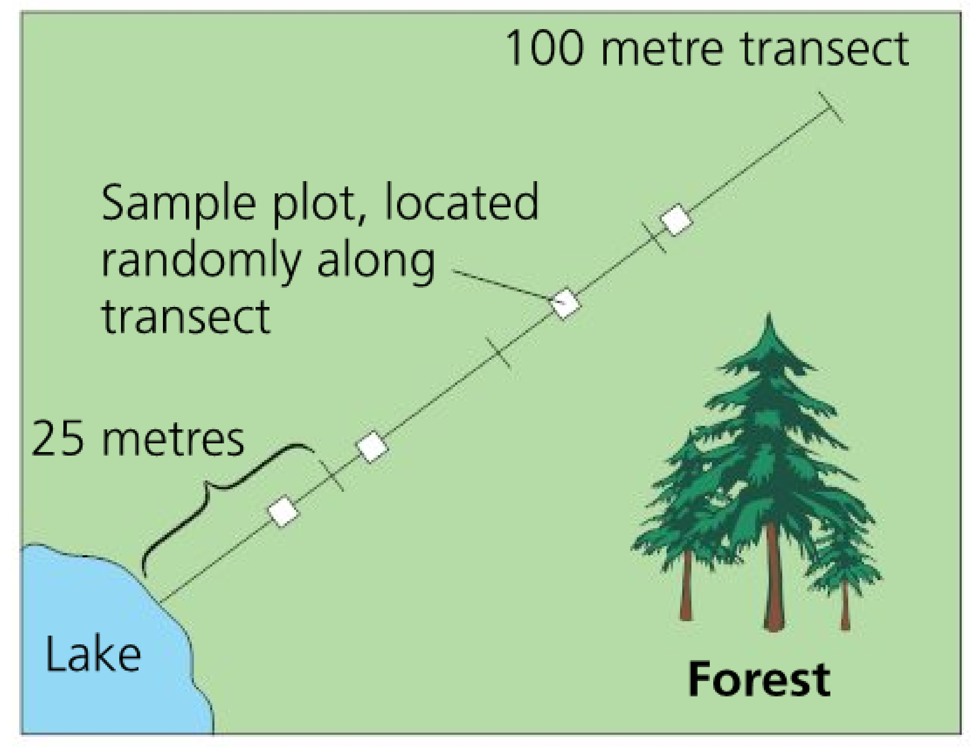


A: Quadrats	B: Number of samples
1	X
2	Y
3	Z

Quadrat random sampling technique, to estimate the number of species in a large area

1. Choose the area in a field that you would like to sample.
2. Lay down two long measuring tapes in an 'L' shape to border this area.
3. Generate two random numbers within the limit of your measuring tapes.
4. Find one number on one measuring tape and another number on the other measuring tape, and find the place in the middle where they both meet (in the diagram, the first quadrat is placed 2 m across and 2 m down).
5. Lay down your quadrat in this area (there are different sized quadrats; the most commonly used one is a 1 m^2 quadrat).
6. Count the samples you find in this area and note the number in a table.
7. Repeat this in a few other random sampling quadrats, noting down the number in each quadrat.
8. Add up all the numbers from the quadrats you counted (x + y + z) and divide this number by the number of quadrats (in this example divide by 3); this will give you the average number of the species in 1 m^2.

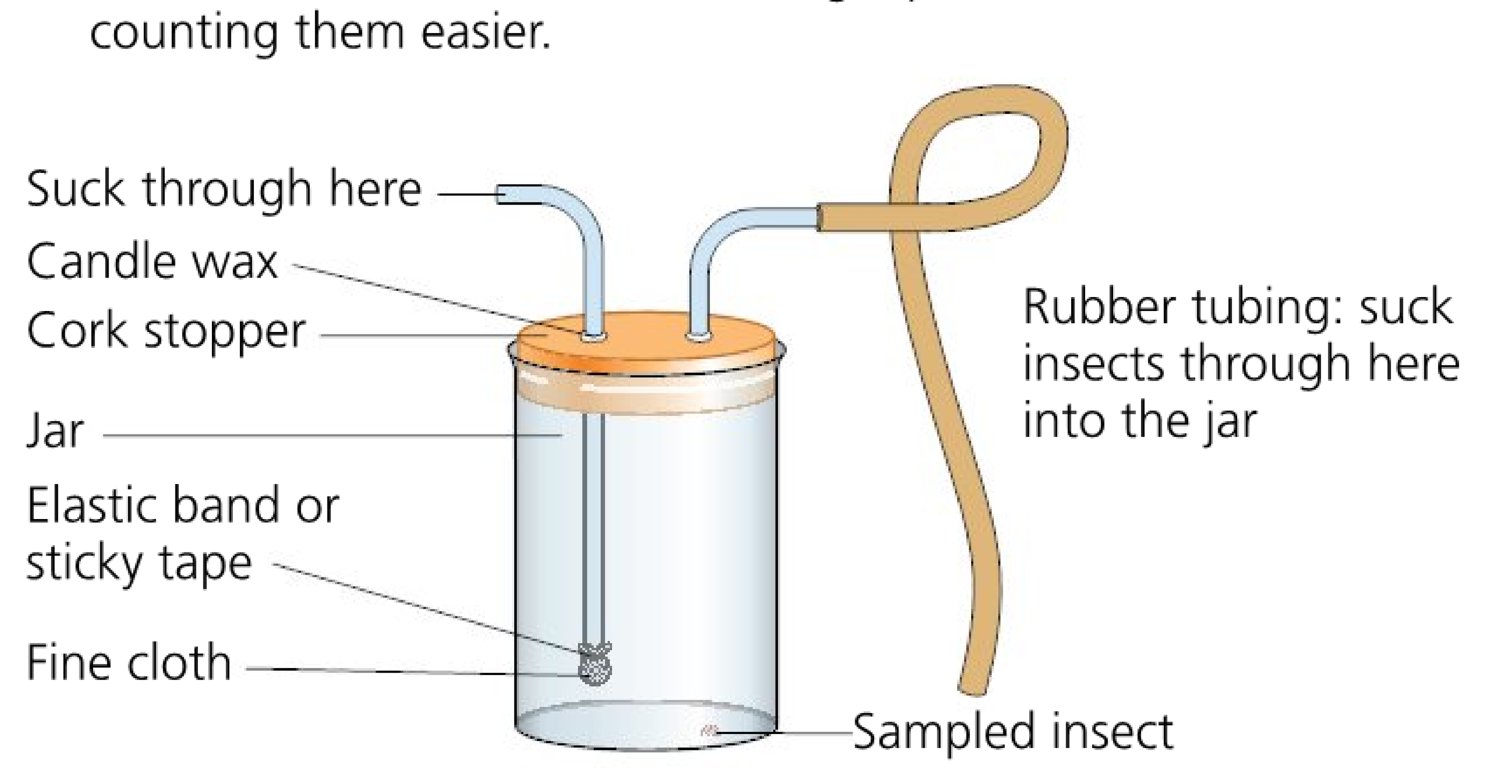
(b) sampling along a transect



Lay down a long measuring tape away from one area (here, the lake), and lay down your quadrats at various distances from it. It can be 10, 20, 30 m, etc. or it can be 1, 2, 3 m, etc., depending on the length of transect you would like to study. This gives you an estimate of the presence of your species as you go further from a starting point.

(c) sampling for insect species

Small insects can be collected using a pooter which can make counting them easier.



■ **Figure 11.5** Methods of sampling: (a) a quadrat, (b) sampling along a transect, (c) sampling for insect species

◆ Assessment opportunities

- This activity can be assessed using Criterion B: Inquiring and designing and Criterion C: Processing and evaluating.

EXTENSION

Ecologists often use statistical methods to establish the reliability of their results. You will encounter these tests if you continue your study in DP Biology, Geography or Environmental systems and societies. Some of the most common statistical tests in ecology are the chi-squared test, t-test, Spearman's Rank correlation and Simpson's index. Note that each different type of data requires a specific test. You may find the following site useful: **www.dataanalytics.org.uk/Data%20 Analysis/Statistics/choosing-your-stats-test.htm**

! Take action: Take part in your local conservation programme

ATL

- Transfer skills: Inquire in different contexts to gain a different perspective
- Communication skills: Negotiate ideas and knowledge with peers and teachers
- Collaboration skills: Take responsibility for one's own actions; Encourage others to contribute; Exercise leadership and take on a variety of roles within groups

! Conservation programmes seek to limit the human impact on ecosystems and biodiversity. As a caring citizen, look for and find a conservation programme in your local area. **Discuss** with your service learning coordinator at school how to arrange for a whole grade or a whole school involvement in this local conservation programme.

! There are also a number of global initiatives you may wish to explore, if your school is not already involved. Try some of these websites for ideas:

World Wildlife Fund project ideas:
http://wwf.panda.org/about_our_earth/teacher_resources/project_ideas/

Eco-schools in the United Kingdom:
www.eco-schools.org.uk/

Green schools alliance:
www.greenschoolsalliance.org/home

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion D: Reflecting on the impacts of science.

FEEDING THE WORLD

By mid-2015, the global population reached 7.3 billion, an increase of approximately 1 billion people in the previous 12 years. By 2030, another 15 years after that, the population is expected to further increase to a total of 8.5 billion. This rapid increase in mouths to feed, energy needs for transport, heating and cooling, and homes for shelter is placing more and more strain on our natural resources. Today, we use the equivalent of 1.5 planets to meet our needs, which means that it takes one and a half times longer to regenerate the resources that we use in a year; by 2030, it is predicted that we will need two planets to meet the needs of our consumption.

In Chapter 10, we looked at the nitrogen cycle and the importance of being able to convert nitrogen from the atmosphere into a soluble form that can be taken up by plants in order to sustain human life. The natural processes that can 'fix' nitrogen (lightning, nitrogen-fixing bacteria and the breakdown of dead organic matter) have never been sufficient to provide us with the amount of food we need, so we have always relied on the use of fertilizer to increase natural yields. When World War I restricted access to the only form of fertilizer available, Germany had a choice to face – let people suffer starvation or solve a problem that no one had been able to until that point. In the following activity, you will explore how one of the most significant industrial processes ever to be created came to be.

SEE–THINK–WONDER

Look at Figure 11.2 on page 293. What do you **see**? What do you **think** about that? What does it make you **wonder**?

ACTIVITY: Natural versus synthetic fertilizer

ATL

- Critical-thinking skills: Revise understanding based on new information and evidence; Draw reasonable conclusions and generalizations
- Transfer skills: Change the context of an inquiry to gain different perspectives; Make connections between subject groups and disciplines

In the nineteenth century, a substance called guano was shipped around the world from South America. This natural nitrate had two crucial applications: it was used as a natural fertilizer and also to make explosives. When the deposits of guano dwindled, caliche replaced it.

1 **Outline what guano and Chilean caliche are.**
2 **Describe why natural fertilizer is important for crop growth.**

Read the following article: **www.theguardian.com/science/the-h-word/2014/jun/02/caliche-great-war-first-world-war-conflict-mineral**

3 **Outline the events that led to the war of the Pacific and Chile expanding its territory.**
4 **Describe how Germany ended up with zero nitrate exports in 1915 (from 33 per cent of the market in 1911).**
5 **Suggest what some of the impacts of the blocked trade routes would have been on the people of Germany at the time.**
6 **Describe what the Haber process is.**
7 **Formulate a balanced symbol equation for the reaction. Identify how this reaction is different from reactions that we have previously seen.**
8 **Identify some of the products that ammonia can be made into.**
9 **State what straight N-fertilizer and NPK fertilizer are. Give examples of compounds that can be found in each.**
10 **Describe why each of the elements in NPK fertilizer are important to plants.**
11 **Research how many people owe their lives to the Haber process. Use this to evaluate the significance of this process.**

Assessment opportunities

- In this activity you have practised skills that are assessed using D: Reflecting on the impacts of science.

Fritz Haber's work led to the discovery of the conditions that enabled the combination of nitrogen gas and hydrogen gas to create ammonia, thereby succeeding in fixing nitrogen artificially. The ammonia was then converted to nitric acid by the Ostwald process. The nitric acid produced became the raw material needed to make the nitrates in fertilizers and ammunition.

The chemical reaction for the Haber process is:

$$N_2\,(g) + 3H_2\,(g) \rightleftharpoons 2NH_3\,(g)$$

The reaction is **reversible**, which means that it never goes to completion. As the nitrogen and hydrogen combine to form ammonia, at some point before the reagents run out, the ammonia molecules start to collide and break down to the initial reactants. Both the forwards and backwards reactions happen at the same time until a **dynamic equilibrium** is reached; at this point, the rate of the forwards reaction is equal to the rate of the backwards reaction so the concentration of the reactants and products does not change.

An example of an equilibrium reaction can be seen between chromate and dichromate ions (Figure 11.6). In acidic conditions, the equilibrium shifts towards the dichromate ions, resulting in an orange colour. Adding an alkali to this will cause the equilibrium to shift to the chromate side, resulting in a yellow colour.

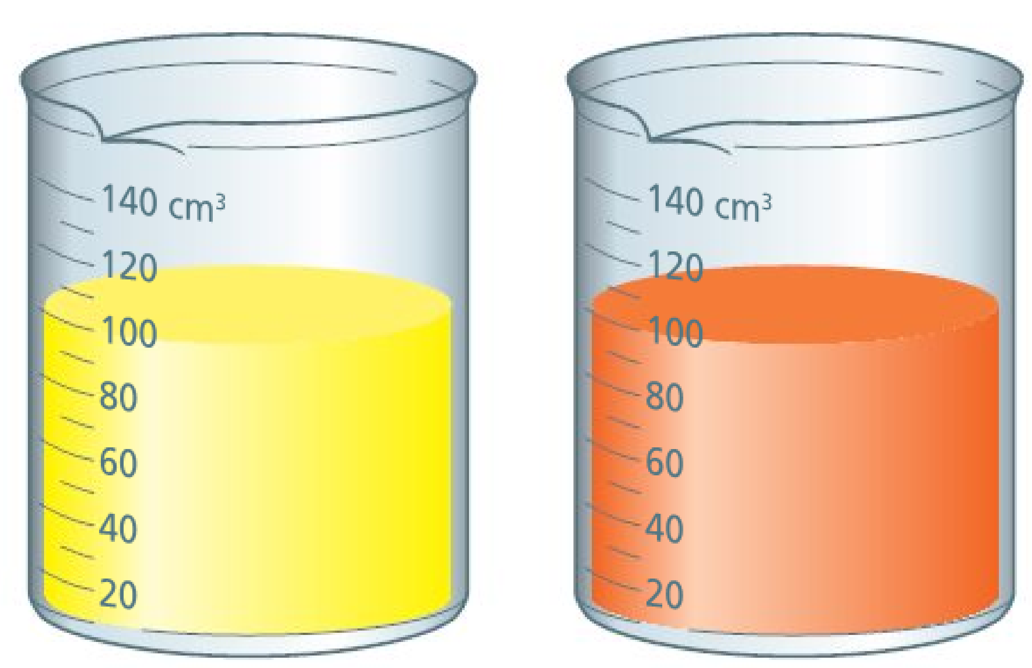
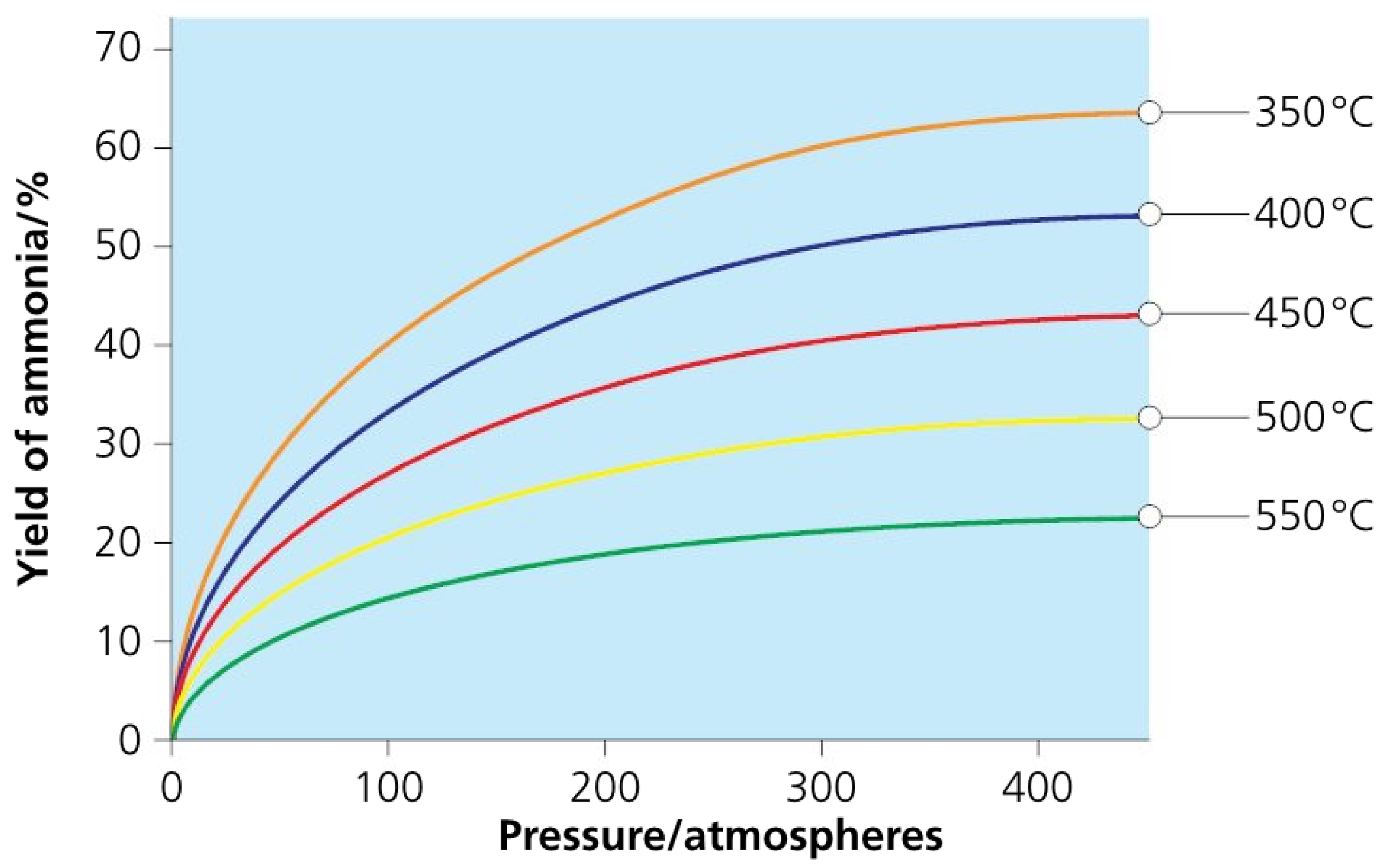


Figure 11.6 A change in the conditions of a reversible reaction can change the position of equilibrium, as can be seen with chromate and dichromate ions

Changing the conditions of a reaction will change the position of the equilibrium. How the position of equilibrium changes with different conditions is governed by **Le Chatelier's principle**. In an industrial process which aims to maximize the **yield** of a useful product, manipulating the conditions according to Le Chatelier's principle plays a significant role.

According to Le Chatelier's principle, when you change the conditions of a system in dynamic equilibrium, the system will always try to shift in a way that restores the equilibrium; in other words, the system will shift to oppose the change.

The Haber process has been studied under a huge range of temperatures and pressures. According to Le Chatelier's principle, the yield of ammonia will be highest at low temperatures with high pressures and if the ammonia is constantly removed as the product. Unfortunately, in reality, the optimum conditions are not necessarily easy to implement.



■ **Figure 11.7** The effect of different conditions on the yield of ammonia

Figure 11.7 shows that pressures as high as 400 atmospheres give the highest yield of ammonia. In reality, building equipment that is capable of withstanding such high pressure is extremely expensive, so a compromise pressure of 200 atmospheres is used in most plants.

Figure 11.7 also shows that lower temperatures favour an increased yield of ammonia. But in Chapter 10, where we focused on the factors that affect the rate of a reaction, we saw that rates are slower at lower temperatures. So while a low temperature would increase the yield of ammonia, the rate of the reaction will be too slow, making the process uneconomical. So a compromise between yield and rate results in a temperature of 450 °C.

In Chapter 10 we also saw that the addition of a catalyst can speed up the rate of the reaction. Finely divided iron is used in the Haber process; a catalyst never has any effect on the position of equilibrium.

Lastly, removing ammonia causes the reaction to shift in the direction of the product. As ammonia has a much higher boiling point than nitrogen and hydrogen, it can be separated easily from the reactants. The Haber process is summarized in Figure 11.8.

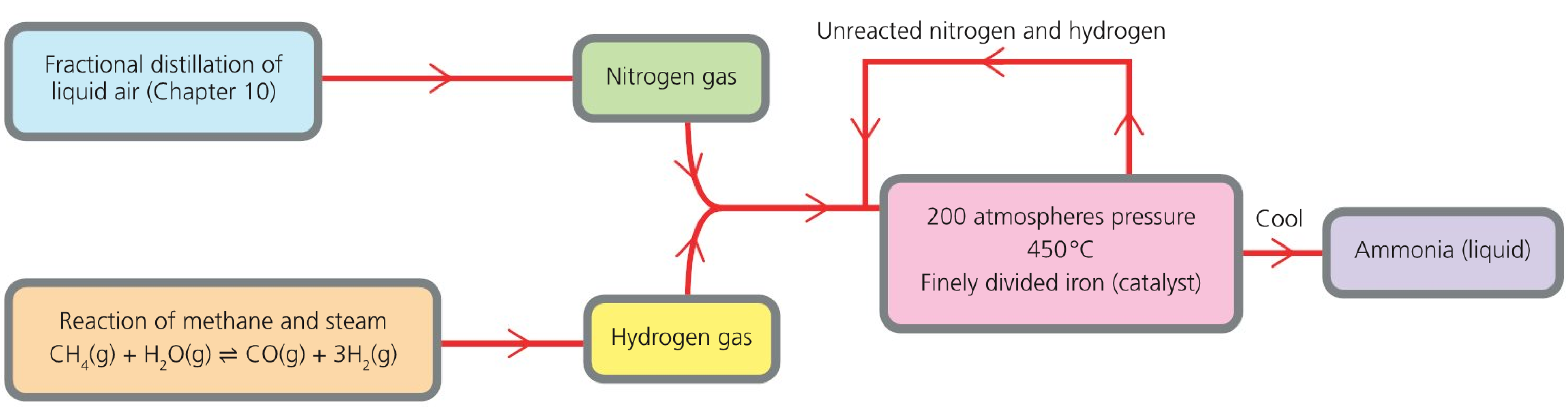
While Fritz Haber came up with the conditions to create ammonia, it was the job of Carl Bosch, an engineer at a German chemical plant called BASF, to solve any engineering problems so that ammonia could be created on an industrial scale. This happened in 1913.

THINK–PAIR–SHARE

Table 11.2 shows how the equilibrium position shifts for different changes in conditions. **Think** of an explanation as to why the equilibrium shifts in this way. Share your ideas in **pairs** and then check them by **sharing** as a class. Some of the examples have been done for you.

Change to the reaction	How the equilibrium shifts	Explanation
Increase the concentration of a reactant.	Equilibrium shifts to the right (direction of the product) and more product is formed.	The system tries to decrease the concentration of the reactant by transforming it into products.
Decrease the concentration of a reactant.	Equilibrium shifts to the left (direction of the reactant) and more reactant is formed.	
Increase the pressure by decreasing the volume.	Equilibrium shifts to the side of the reaction that has the smallest number of molecules of gaseous substances.	Equilibrium shifts to try to decrease the pressure. Pressure in a gas is created by the molecules colliding with the walls of the container. The fewer molecules there are, the lower the pressure will be, so by shifting to the side with the fewest gas molecules, the pressure is reduced.
Decrease the pressure on the system by increasing the volume.	Equilibrium shifts to the side of the reaction with the highest number of molecules.	
How the equilibrium shifts when there is a change in temperature depends on whether the forwards reaction is exothermic or endothermic. If the forwards reaction is exothermic, then it means that the backwards reaction is endothermic.		
Increase the temperature of an exothermic reaction.	Reaction will shift to the reactant side, to the left.	If the forwards reaction is exothermic, overall heat is given out, so you can think of heat being a 'product' of the reaction. So if you increase the temperature, it is like increasing the amount of product.
Decrease the temperature of an exothermic reaction.	Reaction will shift to the product side, to the right.	
Increase the temperature of an endothermic reaction.	Reaction will shift to the product side, to the right.	
Decrease the temperature of an endothermic reaction.	Reaction will shift to the reactant side, to the left.	

■ **Table 11.2**



■ **Figure 11.8** The Haber process

ACTIVITY: Evaluating the use of fertilizers

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument; Evaluate evidence and arguments; Consider ideas from multiple perspectives

Ammonia, the product of the Haber process, is not a fertilizer itself, but is converted into nitrates via nitric acid, made by the Ostwald process. It can be converted into other ammonium products which are also used as fertilizers.

Many fertilizers are made from the reactions of acids and bases. Using your knowledge from Chapter 6, suggest starting materials to make the following fertilizers:

- **potassium nitrate**
- **ammonium nitrate**
- **ammonium phosphate**
- **ammonium sulfate**
- **potassium sulfate.**

Hint

Select an alkali.

Outline as many benefits and limitations of farmers using fertilizers on their crops as you can.

Nitrates are extremely soluble compounds, dissolving readily in the water in soil. This makes it easy for plants to take them up through their roots, but it also means they can easily be washed away by rain, resulting in them entering water and river systems and presenting one of the largest problems associated with the use of fertilizers: eutrophication. Carry out some research to explore this issue further.

Write a summary, **discussing** the benefits and limitations of the use of fertilizers in order to **evaluate** whether farmers should use fertilizers on their crops.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding and Criterion D: Reflecting on the impacts of science.

One of the largest problems with the current processes for making ammonia and fertilizers is that they are extremely energy intensive. Energy intensive processes are associated with emissions of pollutants and carbon dioxide, a greenhouse gas. The following sections will explore these impacts on our natural environment further.

THE GREENHOUSE EFFECT

As we saw in Chapter 10, while the space around the Earth may look empty, it is full of energy. The Earth is constantly bathed in the energy that streams out from the Sun from all parts of the electromagnetic spectrum. If the Earth had no appreciable atmosphere it would be like the planet Mercury – a hot, hard ball of lifeless rock. Earth's atmosphere protects us from solar radiation and life on Earth has evolved so that it is perfectly adapted to the conditions on the surface beneath this protective sunscreen.

Figure 11.9 Sunscreen protects us from the small percentage of UV rays that reach the Earth's surface

The energy that reaches the Earth has been **radiated** across space. Radiated energy can interact with matter in different ways according to the wavelength of the radiation and the properties of the matter. There are three processes that can be used to characterize the interaction of radiant energy with matter.

ACTIVITY: Finding the balance

ATL

- Critical-thinking skills: Analyse complex concepts into their constituent parts and synthesize them to create new understanding

Individually, **analyse** Figure 11.10 showing the way energy is absorbed, reflected or emitted from the Earth–atmosphere system.

In pairs, make a table with three headings: Inputs, Outputs, Stored.

Use your table to **categorize**:

- **sources that add to the energy content of the Earth–climate system**
- **processes that subtract/remove energy content from the Earth–climate system**
- **processes that store energy in the Earth–climate system.**

Now use the values on the diagram to **calculate** the energy balance of the Earth–atmosphere system under the conditions shown. **Comment** on your calculated values.

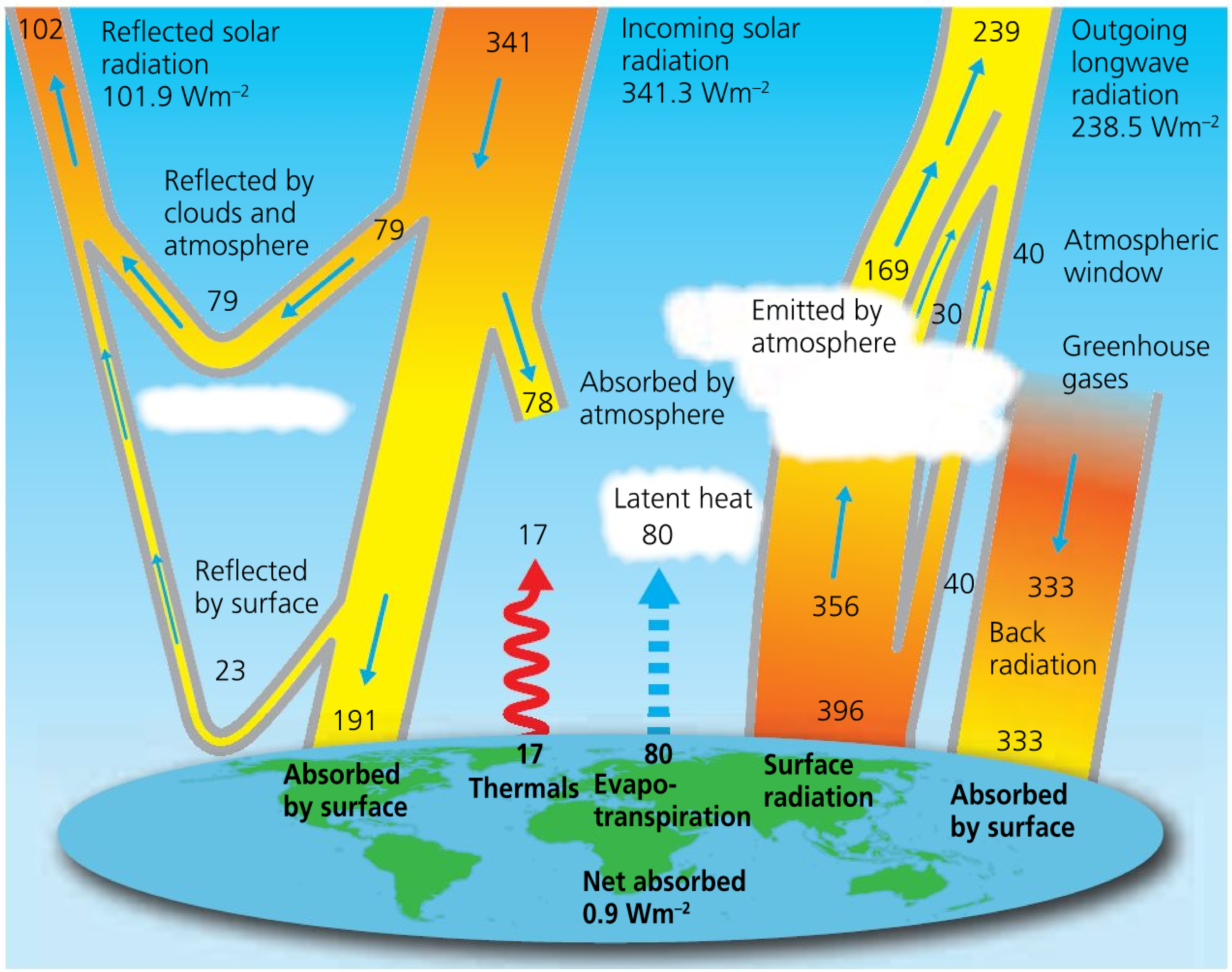


Figure 11.10 Inputs and outputs: climatic energy balance diagram

- **Absorption** means that the radiant energy is taken in by the atoms and molecules that comprise the material. It is converted into kinetic energy in the particles themselves and this means that the temperature of the material increases. The energy which produces this effect is called **infrared** energy since it has a wavelength somewhat longer than the red region of the visible spectrum.
- **Reflection** means that the radiant energy is not absorbed but returned back on its path, without change in properties such as wavelength: a 'mirror-effect', as we saw in Chapter 10.
- **Emission** is where matter gives out radiation. The source of this emitted energy may be energy that was previously absorbed, but on emission its properties have been changed, such as intensity and wavelength. Energy may also be emitted due to processes that are taking place within the matter, for example chemical or nuclear reactions.

ACTIVITY: Radiant surfaces

ATL

- Critical-thinking skills: Interpret data; Evaluate evidence and arguments

Aim: to investigate the interaction between radiant energy and matter.

Equipment

Part 1

- **squares of black, white and silver-coloured card**
- **radiant heat source (electric heater)**
- **timer**
- **lab stand and clamps**

Part 2

- **three metal boxes or glass beakers – one painted black on the outside surface, the second painted white and the third painted silver**
- **polystyrene/styrofoam or cardboard lids for beakers with a hole for thermometer/probe**
- **accurate thermometer or digital temperature sensor with datalogging equipment.**

Hypothesis

Classify each of the three colours (white, black, silver) in terms of their effect on radiant energy. Which will be the best emitter, absorber and reflector? **Explain** your hypothesis, perhaps with reference to examples you have researched.

Method

Part 1

Use a lab stand and clamps to position the three pieces of card a few centimetres from the heat source in a circle.

Turn on the heat source and start the timer.

After a few minutes, gently touch the *back* of the cards with your fingers. What do you observe?

Safety: The cards could become quite hot so ask your teacher to suggest an appropriate amount of time for heating them.

Place a sensitive temperature sensor close to the backs of the cards and measure the temperature of the air behind them.

Record your observations.

Part 2

Measure small amounts of water at room temperature and put the water in each of the three coloured containers. Place the lids on the containers and insert the thermometer/temperature probe.

Position the containers around the radiant heat source in a circle at equal distances.

Turn on the radiant heat source. Measure the temperature at suitable intervals or datalog.

Continue until you think a significant effect has occurred.

Turn off the radiant heat source.

Continue to measure the temperature at intervals or datalog as the water cools back to room temperature.

Results

Organize and **present** your data in a way that allows you to clearly **analyse** and **compare** the outcomes for each of the containers. Include **measurement uncertainties** as appropriate.

Analysis

Analyse your data to **compare** the effects of the coloured surfaces on heating and on cooling. Try to **quantify** the effects so that you can **compare** with actual values, rather than qualitatively.

Conclusion

Write a conclusion about the effect of the different coloured surfaces on radiant energy with reference to your analysed values. **State** whether your hypothesis was correct and **explain** your reasoning or make comparisons to similar effects with other kinds of energy.

Evaluation

Evaluate your experiment. What evidence do you see for error? How significant were the measurement uncertainties? What might have caused them?

Suggest improvements to the experiment design that might reduce or eliminate these sources of error.

Assessment opportunities

- This activity can be assessed using Criterion C: Processing and evaluating.

ACTIVITY: Modelling the climate

ATL

- Information literacy skills: Make connections between various sources of information

Figure 11.11 Earth from space

With your partner, **discuss** and **identify** parts of the Earth–atmosphere system that might have an effect on radiant energy.

Use the table headings in Table 11.3 to **compare** the models in the *Radiant surfaces* activity to the real Earth–atmosphere system.

Part of Earth–atmosphere system	Model radiant surface col our	How it affects radiant energy

Table 11.3

The *Radiant surfaces* experiment shows us that different surfaces have very different effects. Of course, the Earth–atmosphere system does not have uniform black, white and silver surfaces, but there are surfaces in the Earth–atmosphere system that might behave in a similar way to these colours. The experiment can work as a first approximation 'modelling' of radiant energy effects.

The **greenhouse effect** has been identified as one of the main processes by which atmospheric heating occurs. We already noted that when a surface emits radiation that it previously absorbed, the properties of the emitted radiation may be different. This is the case for the radiation that is emitted by Earth's land masses. The incident radiation is re-emitted as longer wavelength infrared which in turn can be re-absorbed and re-emitted by certain gases in the Earth's atmosphere. When the infrared is re-emitted, some of it is directed back down towards the Earth's surface rather than out into space. This results in the infrared radiation becoming 'trapped' near to the Earth's surface and so the average temperature of the troposphere increases. This phenomenon is called the 'greenhouse effect' because it is somewhat similar to the way that glass panes in a greenhouse result in raised temperatures for the plants inside – although it is not actually the same effect, since in a greenhouse much of the heating is really due to reduced airflow.

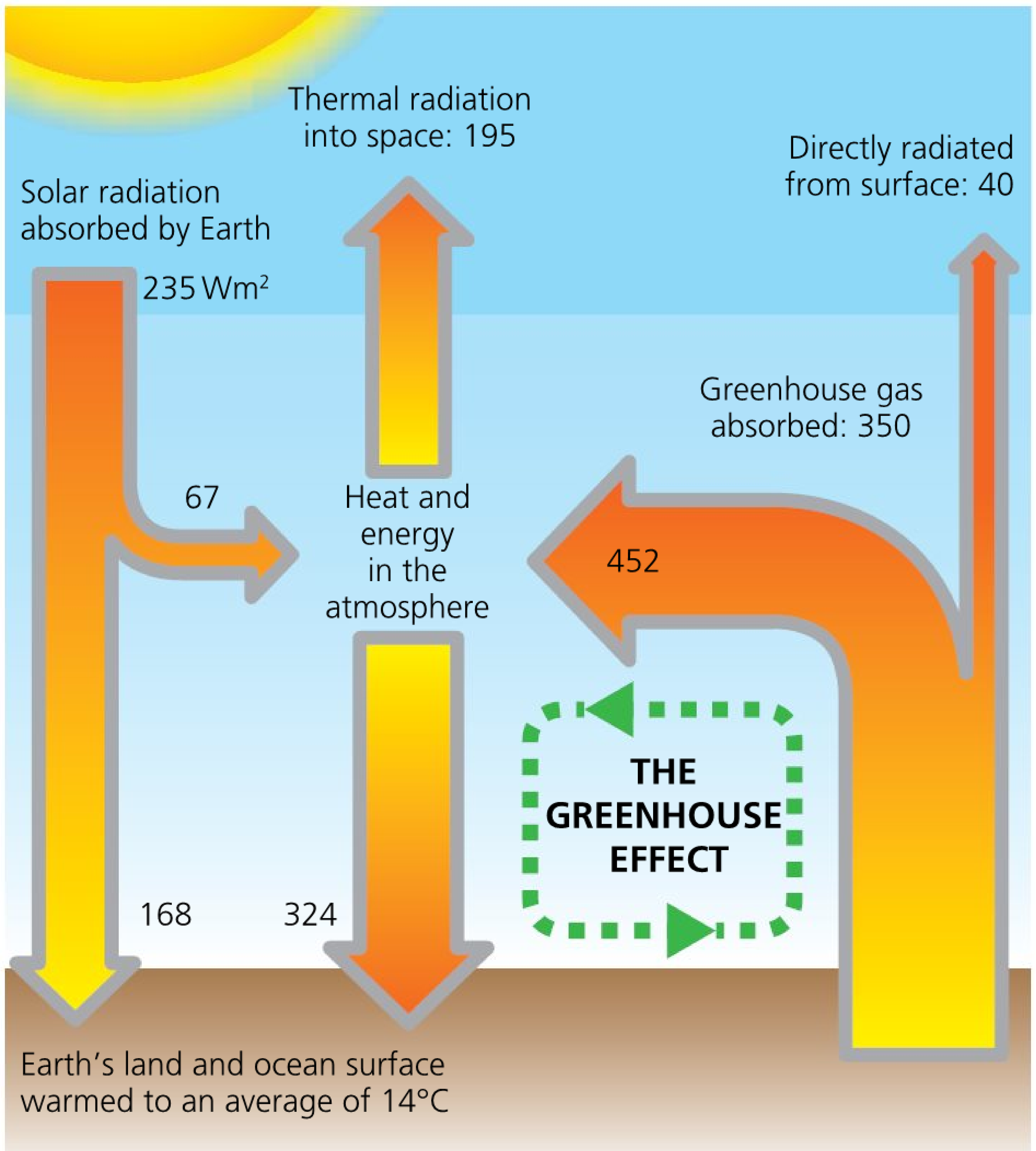


Figure 11.12 Greenhouse effect

ACTIVITY: Guilty gases

ATL

- Information literacy skills: Collect, record and verify data

Warming by the greenhouse effect is caused by the presence of certain gases in the troposphere. The gases identified by climate scientists are shown in Table 11.4. Research **greenhouse gas properties** and then copy and complete the table.

Greenhouse gas	Chemical formula	Concentration in troposphere/ppm*	Effect	Cause(s)
water vapour		depends on conditions		
carbon dioxide		395		
methane		0.002		
ozone		0.0003		

*ppm = *parts per million*, so this is the number of particles of the greenhouse gas found in every million atmospheric particles

Table 11.4

The greenhouse effect is a natural process; without it the Earth's climate would not be so hospitable to life as we know it. However, as you may have explored in *MYP Sciences by Concept 1:* Chapter 6 and *MYP Sciences by Concept 2:* Chapter 5, human activity is increasing the quantities of greenhouse gases in the atmosphere such that the Earth's temperature is increasing rapidly. This is known as the **enhanced or anthropogenic greenhouse effect** and is another example of human impact on the Earth's ecosystems.

Figure 11.13

WHAT MAKES YOU SAY THAT?

Look at Figure 11.13. What's going on? What do you see that makes you say that?

ATMOSPHERIC POLLUTION

Any substance that has an adverse effect on the environment is referred to as a pollutant. Air pollutants have always been present in our atmosphere as they are produced by natural events, such as volcanic eruptions, forest fires and the decay of biological material. However industrialization has led to a dramatic increase in the level of anthropogenic emissions of air pollutants.

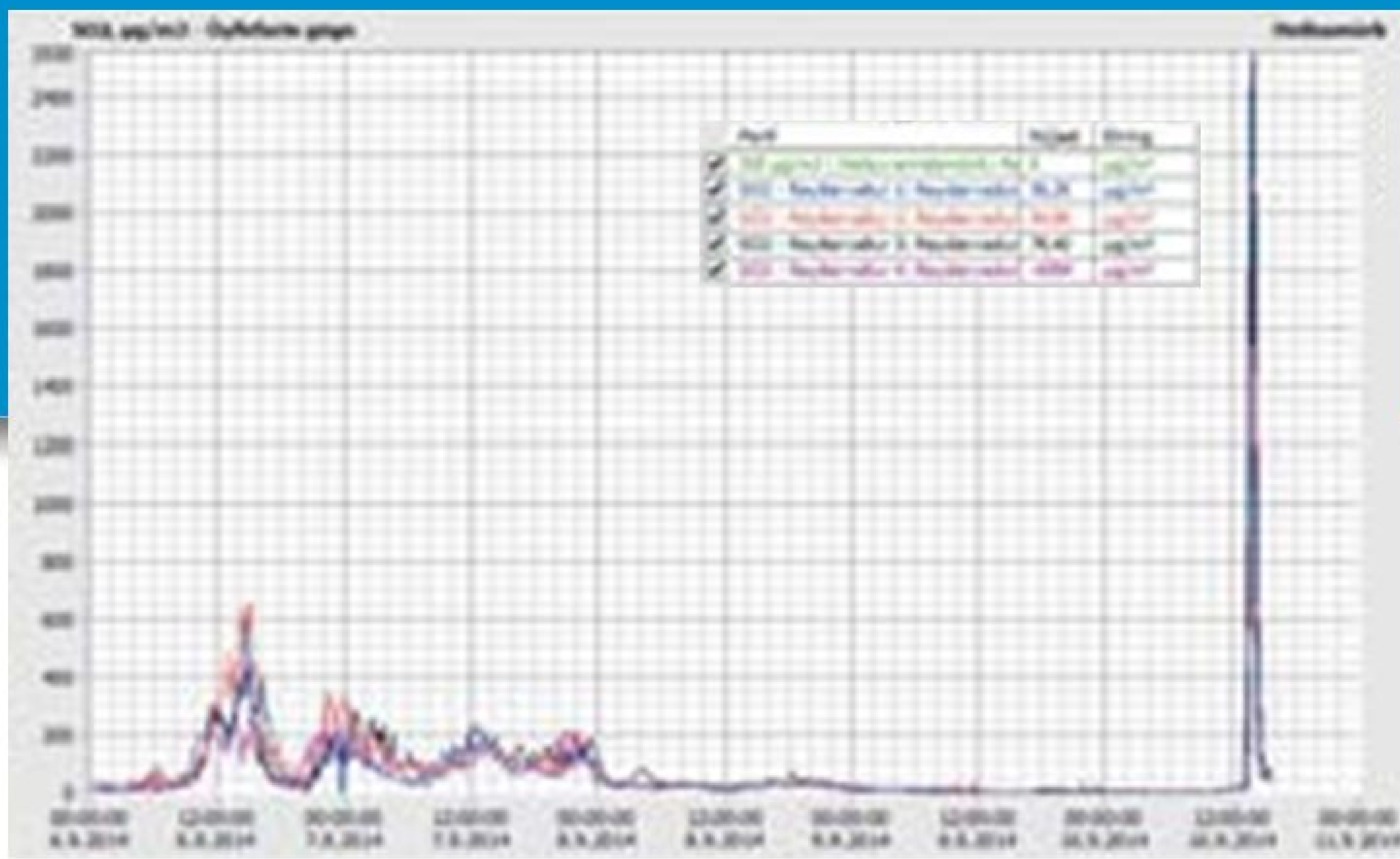
According to the WHO (World Health Organization), 7 million people die every year from air-pollution-related diseases. Further, air pollutants are also causing an adverse effect on our climate. So what are these pollutants, where do they come from and what can we do about them?

Sulfur dioxide

Sulfur dioxide is a pollutant formed during the combustion of specific fossil fuels. This is because the element sulfur can be present in coal and crude oil, so when the fossil fuel is combusted to provide energy, the sulfur also reacts with the oxygen to produce sulfur dioxide.

$$S (s) + O_2 (g) \rightarrow SO_2 (g)$$

Emissions of sulfur dioxide are minor when it comes to transport as the sulfur is often removed before the crude oil is refined, but heavy fuel oil used by ships can contain sulfur. A further source of anthropogenic sulfur dioxide is the extraction of metals from sulfide ores. Significant amounts of sulfur dioxide are also



■ **Figure 11.14** The spike in sulfur dioxide emissions, from 0 to 2550 µg m^{-3}, as the Holuhraun volcano erupted in Iceland. The eruption began on 29 August 2014 and ended on 27 February 2015.

produced naturally by volcanic eruptions and geothermal hot springs as well as from the oxidation of hydrogen sulfide, produced by biological decay.

Sulfur dioxide emissions have impacts on human health as well as ecosystems. Human impacts include damage to the respiratory system, having a particularly adverse effect on children, the elderly and people with asthma. But one of the biggest concerns regarding emissions of sulfur dioxide is its contribution to **acid rain**.

Find out more about the effects of acid rain by watching this video: **www.youtube.com/watch?v=Nf8cuvl62Vc**

Oxides of nitrogen

Oxides of nitrogen (NO_x) are another group of pollutants. These include nitrogen monoxide (NO) and nitrogen dioxide (NO_2). Oxides of nitrogen are formed when nitrogen and oxygen gas react together. Now 99 per cent of our atmosphere is made up of these two gases, but they do not react together under normal conditions because of the strong triple bond in a molecule of nitrogen (Chapter 4) which requires a lot of energy to be broken (Chapter 5). Lightning (Chapter 10) and forest fires can provide this energy naturally. Engines and combustion processes also provide the necessary high temperatures.

$$N_2\ (g) + O_2\ (g) \rightarrow 2NO\ (g)$$

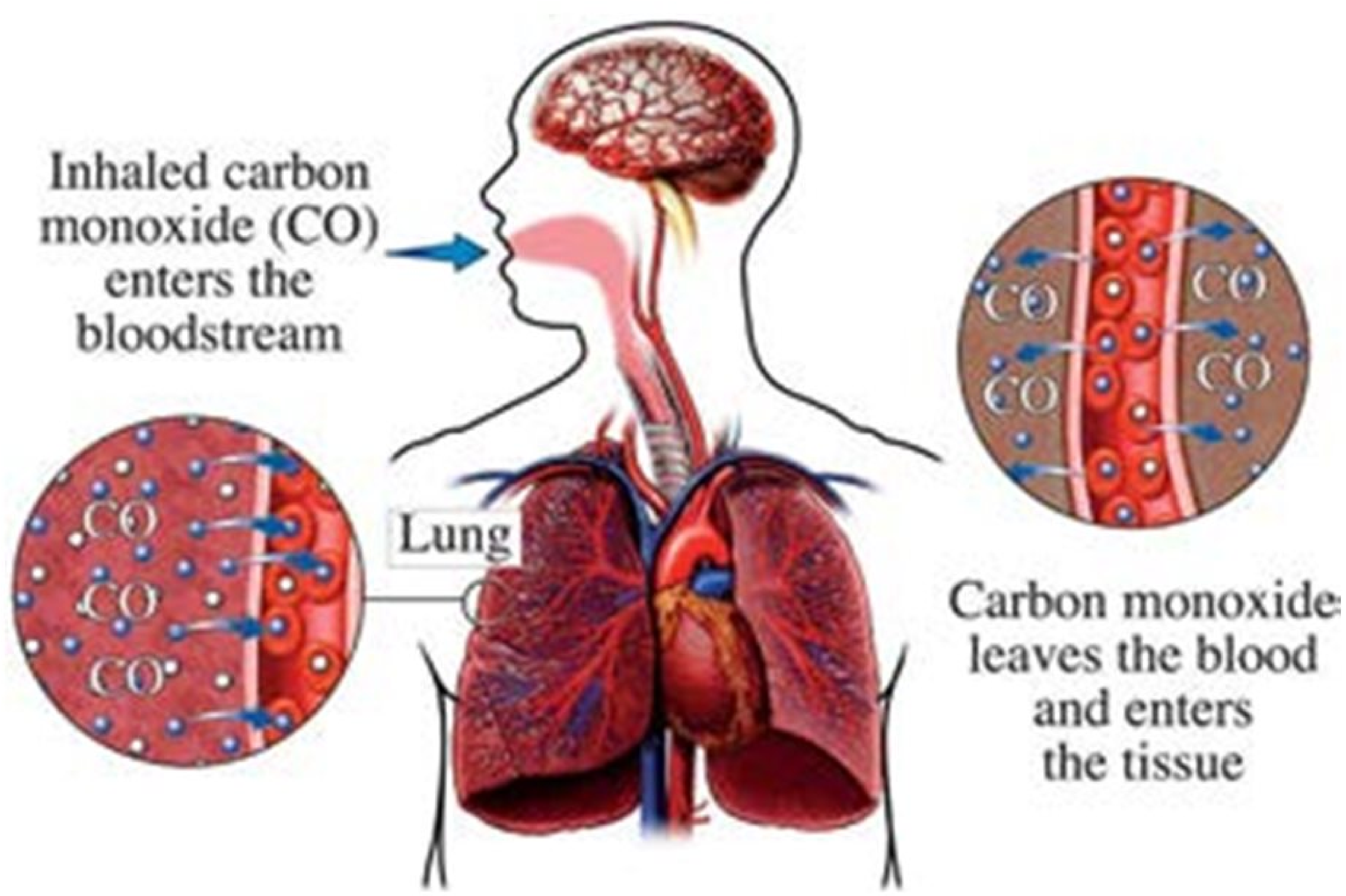
Nitrogen monoxide is not a harmful gas in itself. However, it quickly oxidizes to nitrogen dioxide in the presence of oxygen, and nitrogen dioxide has a similar effect on the respiratory system as sulfur dioxide and also contributes to acid rain. Further, NO_x emissions are linked to the formation of other pollutants: fine particulates and ground level ozone. Currently, emissions of NO_x from vehicles are the greatest causes of concern to human health and the environment.

$$2NO\ (g) + O_2\ (g) \rightarrow 2NO_2\ (g)$$

Carbon monoxide

We know that the combustion of any fossil fuel produces carbon dioxide. While carbon dioxide is not a pollutant (it is a greenhouse gas), in the absence of oxygen, incomplete combustion occurs and carbon monoxide is produced. Carbon monoxide is a lethal pollutant. Hemoglobin in our blood will combine with it more readily than oxygen, preventing the transport of oxygen around the body which can result in death; even being exposed to very small amounts of carbon monoxide can lead to dizziness. Being colourless and odourless makes it particularly dangerous. Any natural combustion process, for example forest fires or volcanoes, where oxygen is limited will result in the production of carbon monoxide.

$$2CH_4\ (g) + 3O_2\ (g) \rightarrow 2CO\ (g) + 4H_2O\ (l)$$



■ **Figure 11.15** Carbon monoxide poisoning

Figure 11.16 Piccadilly Circus during the Great London Smog of 1952

Particulates

The incomplete combustion of fossil fuels can also lead to the emission of particulate matter. Particulate matter consists of any solid or liquid particles that are found in the air. These include particles of a range of sizes, from dust, soot and smoke that are large enough to see, to particles that can only be seen using an electron microscope. It is the small size of these particles that makes them so dangerous to human health as they are able to get into our lungs and even into our bloodstream. They are produced naturally by volcanic eruptions, as well as through sea-spray and any dust carried by the wind.

EXTENSION: GOING FURTHER

Unfortunately, instead of taking a proactive approach to protecting ourselves and our environment, when it comes to issues of pollution we often take action as a consequence of unfortunate events. This was the case with the Great London Smog of 1952 (Figure 11.16). The term smog comes from 'smoke' and 'fog'. While London was renowned for its fog, this one was toxic and in the four days before it lifted and in the ensuing weeks, it is thought to have caused up to 12 000 deaths and led to more than 150 000 people being hospitalized, as well as the death of many animals. With people heating their homes with coal with a high sulfur content, and the presence of a number of power stations within the city, huge amounts of sulfur dioxide and smoke were being emitted every day. The result was the introduction of the Clean Air Act, 1956, which introduced smoke control areas in some towns and cities, where only smokeless fuels could be burnt; it also controlled chimney heights.

DISCUSS

1 **Use all the information in the text to create a summary table of pollution. Your table must include the name and formula of each pollutant, both its natural and anthropogenic sources, as well as its effects.**
2 **Identify which pollutants are primary and which are secondary, and add this to your table.**
3 **Explain how acid rain is formed, describe its main impacts and suggest why the impacts of acid rain may not necessarily be experienced at the source of pollution.**

Particulates can be emitted as **primary** or **secondary pollutants**. Particulates can cause buildings to appear dirty as they get coated with soot. They are also the main cause of reduced visibility. But it is the effects on human health that cause the greatest concern; able to penetrate the respiratory system, short-term exposure can lead to irritation, especially among individuals who are vulnerable, but long-term exposure can lead to cardiovascular and respiratory diseases that can be fatal, as well as lung cancer. Until recently, major health concerns centred around emissions of PM_{10}. PM_{10} includes all particles with a diameter smaller than $10\,\mu m$. However research has shown that it is particles with a diameter smaller than $2.5\,\mu m$ ($PM_{2.5}$) that are actually responsible for more of the adverse health effects of particulate matter.

EXTENSION

The exact science behind the toxicity of smog has only recently been discovered by studying China's modern air quality issues:

www.sciencealert.com/researchers-have-finally-figured-out-what-caused-london-s-deadly-fog

www.popsci.com/why-is-smog-in-china-so-bad

China's air pollution is already considered a serious problem. Find out what measures China is putting in place to deal with the issue of air pollution.

Ozone

Ozone is another pollutant that is closely monitored because it is a constituent of photochemical smog. Photochemical smog is formed by the chemical reaction between oxides of nitrogen (NO_x) and volatile organic carbons (VOCs) in the presence of sunlight, which creates particulate matter and ozone. For this reason, ozone is classed as a secondary pollutant because it is not emitted directly into the air. The effects of ozone on human health include irritation and inflammation of the lungs, which can lead to coughing and general discomfort, with people suffering from asthma, children and the elderly being most vulnerable. It can also have an adverse effect on vegetation and ecosystems.

EXTENSION: GOING FURTHER

Find out how lichens can be used as **bioindicators of pollution**.

Read the article and **evaluate** the use of biomonitors for air pollution: **www.flanderstoday.eu/education/strawberry-plants-measure-air-quality**

EXTENSION: GOING FURTHER

If you have ever visited a petrol station, you may have noticed that petrol is 'unleaded'. This has not always been the case and still isn't in some countries. Carry out some research to find out why lead used to be deliberately added to petrol and what some of the effects of lead poisoning are, leading it to being phased out across most of the world from the early 2000s.

ACTIVITY: Pollution (and acid rain) solution!

ATL

- Communication skills: Use and interpret a range of discipline-specific terms and symbols; Paraphrase accurately and concisely
- Critical-thinking skills: Practise observing carefully in order to recognize problems; Gather and organize relevant information to formulate an argument

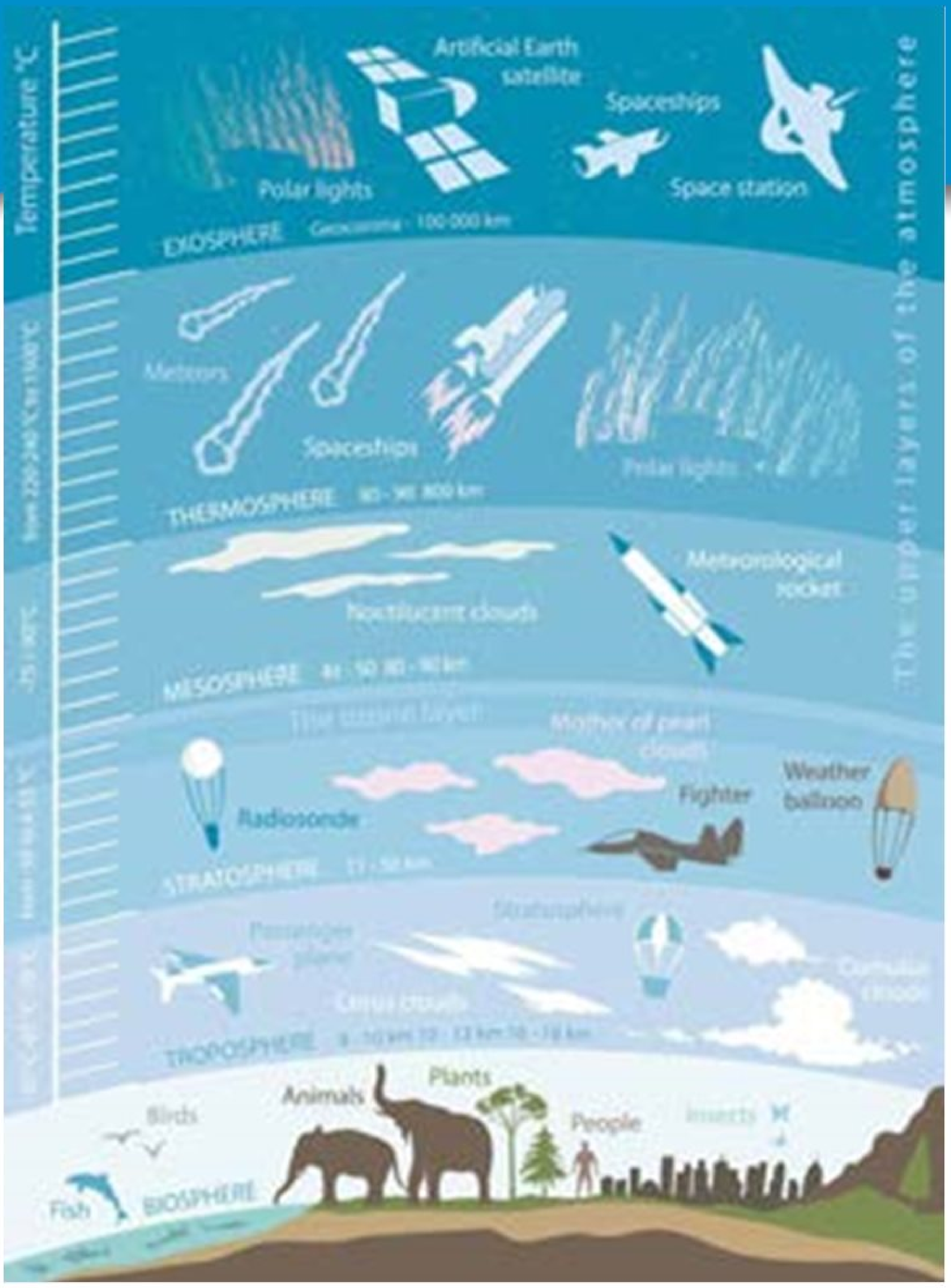
The best way to reduce the impact of acid rain is to prevent the emission of sulfur dioxide and oxides of nitrogen. There are a number of methods that are used in industry to accomplish this, which include scrubbing, hydrodesulfurization and catalytic converters, which you will focus on in this task.

These three technologies are summarized here: **www.youtube.com/watch?v=VILCk2CpUCw&t=3s**

Use the information in the video and your own research to write a report on the efficacy of *one* of these methods. **Explain** the science behind it, **discuss** and **evaluate** the impact. **Comment** on the role that political factors play in the adoption of such technologies globally.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion D: Reflecting on the impacts of science.



■ **Figure 11.17** Principal layers of the atmosphere

THE OZONE LAYER

Ozone, whose presence can have such detrimental effects in the troposphere, provides a lifeline for us up in the stratosphere. This is because ozone absorbs some of the Sun's harmful UV radiation, greatly reducing the amount reaching the Earth's surface.

Ozone (O_3) is formed when an oxygen molecule combines with an oxygen atom. The oxygen atom is produced when UV light splits an oxygen molecule into oxygen atoms.

$$O_2\,(g) \rightarrow O\cdot(g) + O\cdot(g)$$

$$O_2\,(g) + O\cdot(g) \rightarrow O_3\,(g)$$

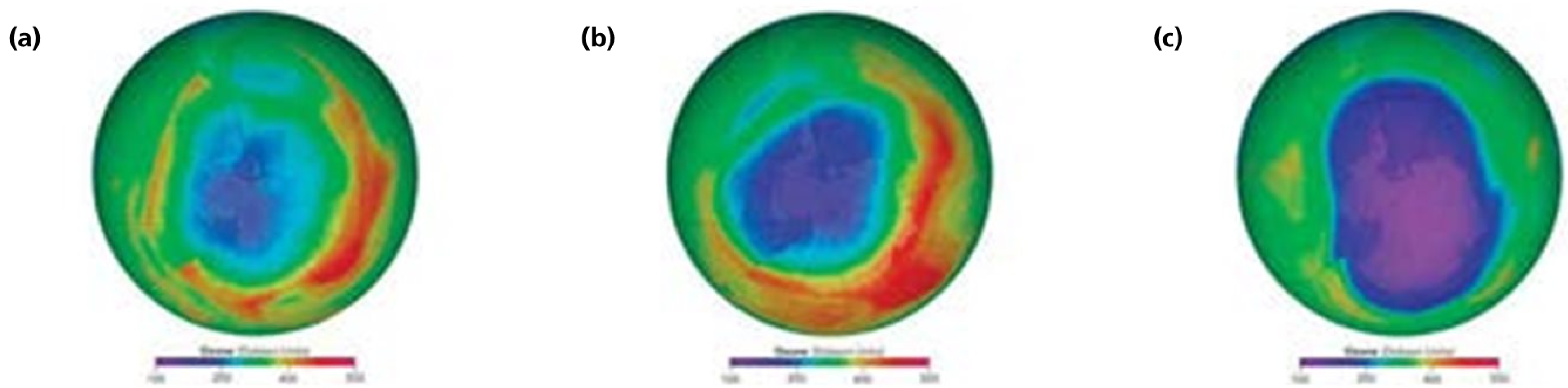
The process is reversed when ozone is naturally broken down by UV radiation. The formation and breakdown of ozone creates a natural cycle, keeping levels approximately constant for millions of years. But in the 1980s scientists found evidence of a 'hole' or thinning in the ozone layer and this topic dominated scientific news and discussions for much of the decade, as concentrations of ozone plummeted.

ACTIVITY: How can we solve a problem like the thinning of the ozone layer?

ATL

- Communication skills: Make inferences and draw conclusions

1 **Describe** the changes in ozone concentration at the South Pole between 1980 and 2006, using the images in Figure 11.18.



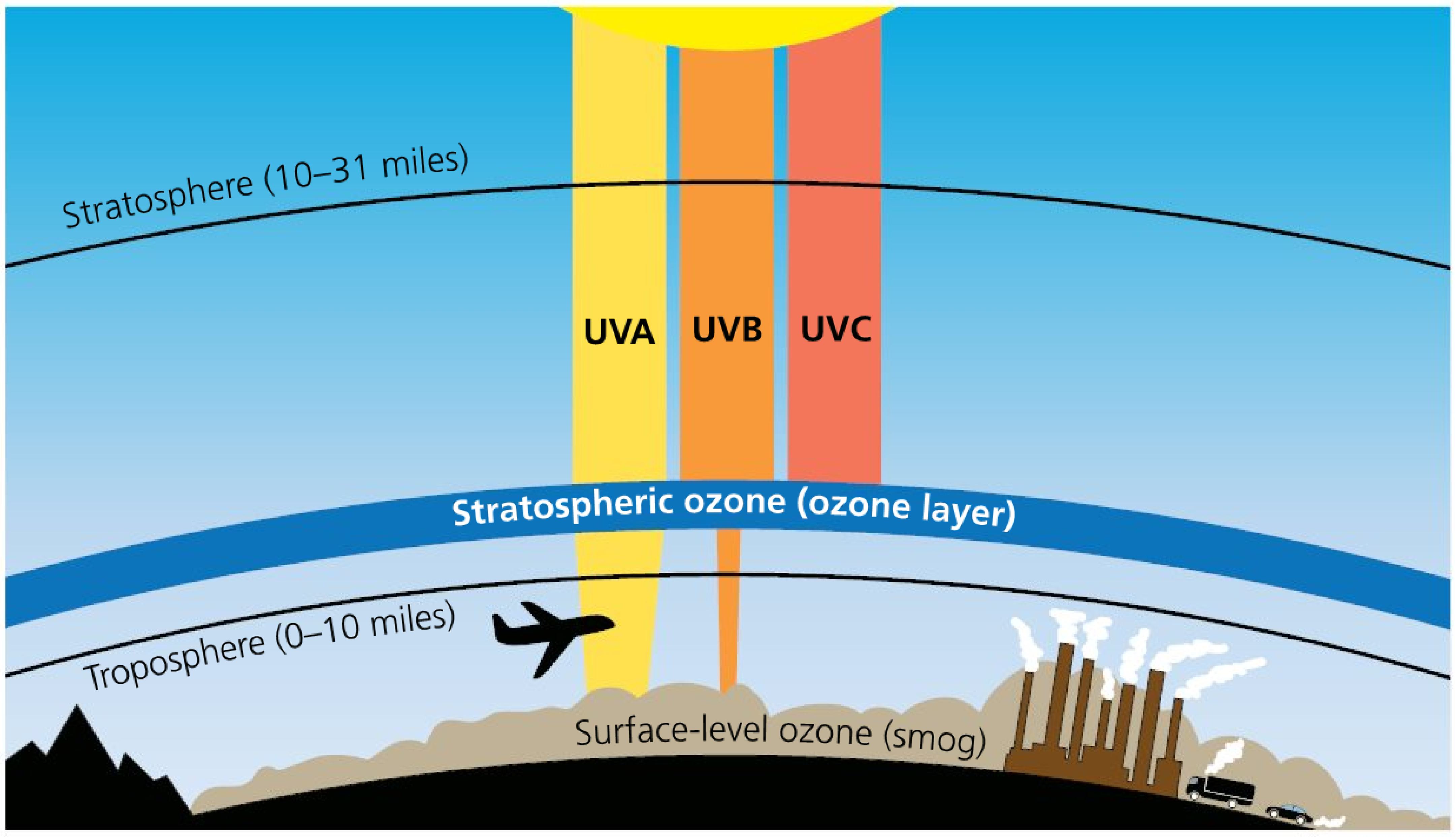
■ **Figure 11.18** Ozone concentrations over the South Pole in (a) 1980, (b) 1988 and (c) 2006

2 **Outline** how scientists measure ozone concentrations by carrying out an internet search.

3 **Describe** what Figure 11.19 shows about the types of UV radiation and the effect of the ozone layer on them.

4 In the 1970s, scientists discovered that ozone was being rapidly broken down by substances called CFCs. Find out what CFCs are, what they were used for and **explain** the science behind their effect on ozone.

5 'Perhaps the single most successful international agreement to date has been the Montreal Protocol.' These were the words of Kofi Annan, the former Director General of the United Nations. **Evaluate** the effect of the Montreal Protocol and why it is considered so successful.



■ **Figure 11.19** The effect of the ozone layer on different types of UV radiation

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding and Criterion D: Reflecting on the impacts of science.

Should scientists be held accountable for how their discoveries are used?

! Take action: Act it out!

ATL

- Communication skills: Collaborate with peers and experts using a variety of digital environments and media; Use a variety of speaking techniques to communicate with a variety of audiences
- Collaboration skills: Help others to succeed; Take responsibility for one's own actions; Manage and resolve conflict and work collaboratively in teams; Listen actively to other perspectives and ideas
- Creative-thinking skills: Create original works and ideas; Use existing works and ideas in new ways; Practise flexible thinking – develop multiple opposing, contradictory and complementary arguments
- Information literacy skills: Create references and citations, use footnotes/endnotes and construct a bibliography according to recognized conventions

! In this task the class will be performing role plays of discussions between the following characters:

- **Fritz Haber** and his wife, **Clara Immerwahr**

CIRCLE OF VIEWPOINTS

As a class, brainstorm different viewpoints on this topic. Consider viewpoints that exist today as well as viewpoints that would have existed in the past. Consider viewpoints in times of war and peace. Consider different perspectives – that of the inventor but also the general public or anyone who could have been affected by the invention.

In pairs, select one of the viewpoints you have brainstormed.

I am thinking of … [the topic] … *from the point of view of* …

Together you will make a short one-minute presentation to the rest of the class on the topic from the perspective of the viewpoint you have chosen. Try to ensure all of the viewpoints are selected.

I think … [describe the topic from your viewpoint; be an actor – take on the character of your viewpoint]

Finish off by reading this article about some of the greatest scientific inventions that were later regretted by their inventors: **http://bigthink.com/laurie-vazquez/6-scientists-who-regret-their-greatest-inventions.amp**

What new ideas do you have about the topic that you didn't have before? What new questions do you have?

A question I have from this viewpoint is …

Figure 11.20 The mushroom cloud from the second atomic bomb, 'Fat Man', dropped on Nagasaki, Japan on 9 August 1945, which killed over 75 000 people

- **Leo Szilárd** and **J. Robert Oppenheimer** (responsible for the research and design of the atomic bomb)
- **Alfred Nobel** (inventor of dynamite and also the Nobel Prize) with his testator (the person who writes and signs a will)
- **Thomas Midgley Jr** (adding lead to petrol as an anti-knocking agent and using the CFC freon as a refrigerant) and his doctor who treated him for lead poisoning
- **James Buchanan Duke** (the father of the modern cigarette), a man dying of lung cancer who had smoked cigarettes since 1960 and a lawyer for a major tobacco company.

! You will work together in your groups to carry out research about the characters in bold type and then work together to write a script for a role play, before presenting it to the rest of the class.

! Find out about the history of the main characters, the period and country they grew up in, to give context to their work. Feel free to introduce additional characters to your role play.

! Find out about their scientific work; your role play must include brief descriptions of this. As a group consider how they might have felt making the discoveries that they did. At the end of your presentation, take questions from your audience and then provide a brief summary to the class about why you chose to lead the discussion in the direction that you did.

! When planning and writing your scripts, it is important to consider the dates that these conversations were happening and these should be indicated in your presentation (though you may choose to have multiple discussions at different periods in the characters' lives). As the article in the *Circle of viewpoints* activity showed, scientists sometimes had regrets later on in their lives about their inventions.

! Submit a fully documented list of sources to your teacher separately.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion D: Reflecting on the impacts of science.

SOME REVIEW PROBLEMS TO TRY

1 The reaction of sulfur dioxide with oxygen to produce sulfur trioxide is an equilibrium reaction. The sulfur dioxide is created by the reaction of sulfur and oxygen.

a **Formulate** balanced symbol equations for these reactions using state symbols.

b **Predict** whether the reaction is endothermic or exothermic, providing a reason for your answer.

c Four students are trying to deduce the optimum conditions for the reaction to occur.

i Student 1 suggests a pressure of 4 atmospheres and a temperature of 500 °C.

ii Student 2 suggests a pressure of 4 atmospheres and a temperature of 100 °C.

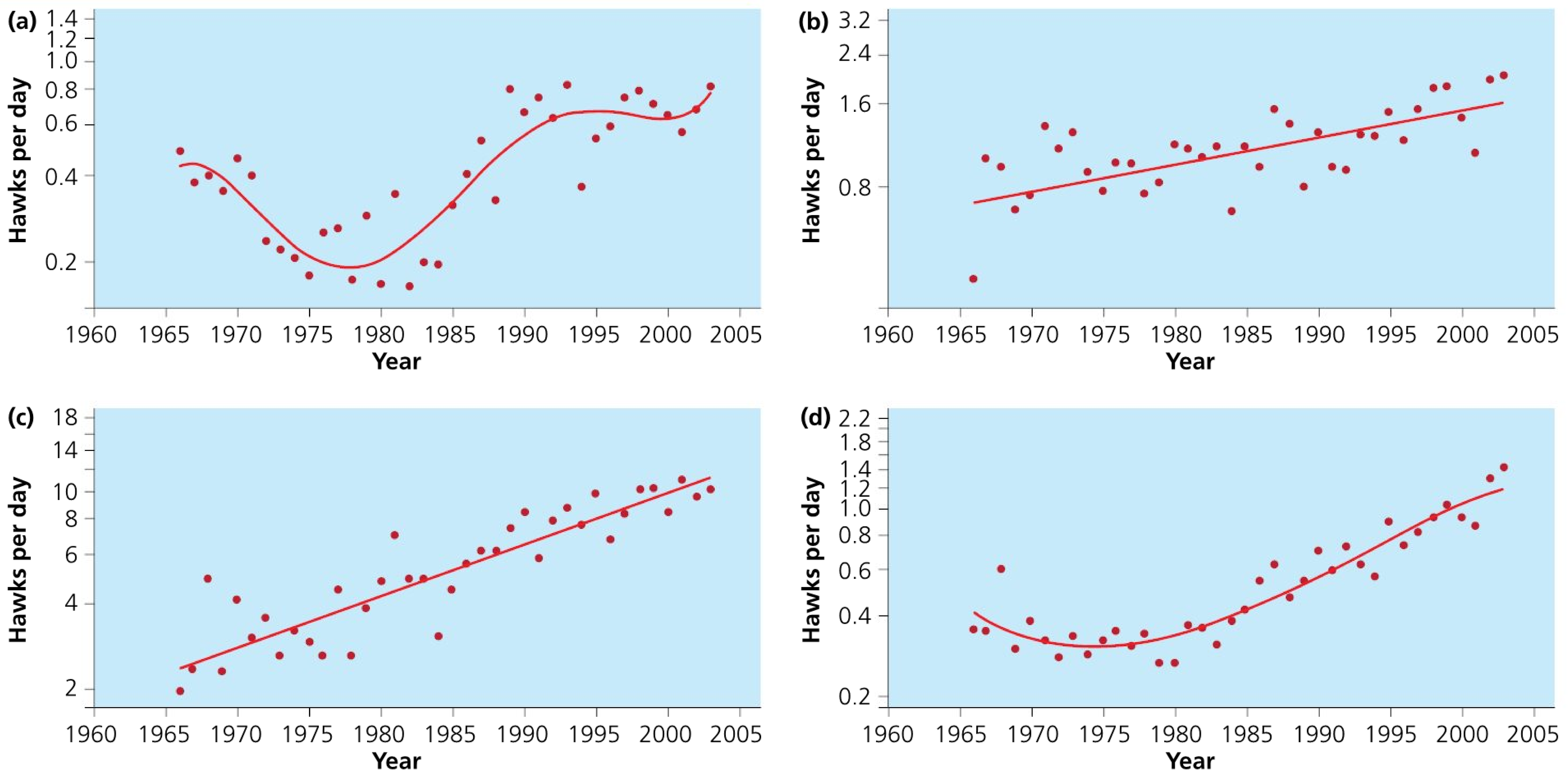
iii Student 3 suggests a pressure of 1 atmosphere and a temperature of 500 °C.

iv Student 4 suggests a pressure of 1 atmosphere and a temperature of 100 °C.

Apply scientific reasoning and understanding to **suggest** which are the more favourable conditions for the reaction, **explaining** your answer.

d Another student suggests a pressure of 4 atmospheres and a temperature of 250 °C; **evaluate** the choice of these conditions against the choice you made in part (c).

e **Explain** why the use of a catalyst will never result in a shift in the position of the equilibrium.



■ **Figure 11.21** Number of birds observed per day (a) Peregrine falcon, (b) Golden eagle, (c) Cooper's hawk, (d) Bald eagle

2 Using pesticides positively impacts productivity of crops but also negatively affects non-targeted organisms. Dichlorodiphenyltrichloroethane (DDT) was one of the first chemicals in widespread use as a pesticide. Following the Second World War, it was promoted as a wonder-chemical to control many pests including disease-causing ones. It led to controlling the spread of typhus and malaria and became the favourite agricultural and household pesticide until concerns were raised about its impact on health and the environment, including endangering some animal species. The data in Figure 11.21 indicate the population trends found for four raptors (birds of prey) in the US.

- **a** **Interpret** the data to **identify** the relationship between the use of DDT since the Second World War and the populations of these birds, then **deduce** which birds were endangered and in which period of time.
- **b** DDT was banned in the US in 1972. **Describe** the effect this event had on the birds.

Other human disturbances have also played a role in the decline of the bald eagle populations in the US. A 'disturbance' is defined as any human activity that causes an eagle to alter its physiological state or behaviour such as disturbance of habitat. Visit the following website to see graphs which show the proportion of bald (white dots in the graphs) and golden (black dots) eagle carcasses with specific primary causes of death between 1975 and 2013 in different regions: **www.researchgate.net/figure/Proportion-of-bald-white-dots-and-golden-black-dots-eagle-carcasses-with-a-primary_fig3_264861144**

- **c** **Compare** and **contrast** the proportion of deaths caused by the various factors shown in the graphs between the golden and bald eagles.
- **d** **State** the regions with maximal and minimal death and **determine** the proportion in each case.
- **e** Use these data to **evaluate** whether DDT alone has caused the decline in eagle populations.

Reflection

In this chapter we have **outlined** how ecologists **describe** relationships between living things using food webs and pyramid diagrams of different kinds. We have **evaluated** the human impacts on ecosystems. We have **collected** data using some of the scientific methods of ecology and **evaluated** the reliability of this data. We have **evaluated** the use of fertilizers and discovered how to create ammonia through the Haber process, **explaining** the conditions selected using Le Chatelier's principle. We have **explained** the effects of greenhouse gases on radiation, absorption and emission from the Earth and we have **outlined** the impact of different greenhouse gases. We have **explained** how pollutants are formed and **outlined** their respective effects on human health and natural ecosystems. We have also **described** what the ozone layer is and how it was being broken down because of the emissions of CFCs into the atmosphere.

In this chapter we have also considered science in times of war, **describing** examples of where science has played a major role in the outcome of conflicts and **presented** the decision as to whether scientists use their work to contribute to war efforts from a range of viewpoints.

<table>
<tr><th colspan="6">Use this table to reflect on your own learning in this chapter</th></tr>
<tr><td>Questions we asked</td><td>Answers we found</td><td colspan="4">Any further questions now?</td></tr>
<tr><td>Factual</td><td></td><td colspan="4"></td></tr>
<tr><td>Conceptual</td><td></td><td colspan="4"></td></tr>
<tr><td>Debatable</td><td></td><td colspan="4"></td></tr>
<tr><td rowspan="2">Approaches to learning you used in this chapter:</td><td rowspan="2">Description – what new skills did you learn?</td><td colspan="4">How well did you master the skills?</td></tr>
<tr><td>Novice</td><td>Learner</td><td>Practitioner</td><td>Expert</td></tr>
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<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Learner profile attribute(s)</td><td colspan="5">Reflect on the importance of being principled for your learning in this chapter</td></tr>
<tr><td>Principled</td><td colspan="5"></td></tr>
</table>

12 How can we use science to make a better future for all?

Science and technology bring about **change for the better** and sometimes only science can resolve the unforeseen **consequences**.

CONSIDER THESE QUESTIONS:

Debatable: How will we make the world of the future? To what extent have scientists learnt from nature? How will we meet the energy demands of the future? How can we live in balance with the natural world? To what extent can we learn from natural systems to harness energy sustainably? To what extent should we modify natural processes to meet our needs? How can we share the world fairly for all? Can countries put their needs aside to work together on global issues?

Now **share and compare** your thoughts and ideas with your partner or with the whole class.

IN THIS CHAPTER, WE WILL …

- **Find out** how scientific and technical innovation might help us to solve the problems created by modern, technological society.
- **Explore** what those problems may be and the different perspectives on them.
- **Take action** to raise awareness of global issues relating to scientific and technical innovation, engage with them and bring about change.

These Approaches to Learning (ATL) skills will be useful …

- Information literacy skills
- Media literacy skills
- Communication skills
- Collaboration skills
- Critical-thinking skills
- Reflection skills
- Transfer skills
- Creative-thinking skills

Assessment opportunities in this chapter:

The activities in this chapter will help you develop and evaluate your learning in these MYP Sciences learning objectives:

- **Criterion A:** Knowing and understanding
- **Criterion C:** Processing and evaluating
- **Criterion D:** Reflecting on the impacts of science

■ **Figure 12.1** The only home we have. Earthrise seen from the Moon by Apollo 8 astronauts in 1968.

● We will reflect on this learner profile attribute …

- Principled – we will consider the consequences of our actions for the world you will inherit in the future.

KEY WORDS

efficiency	globalization
energy	sustainability
exploit	sustainable development

This final chapter is going to be a little different. In the pages that follow you will find ideas for activities and projects which all relate to ways in which science has brought about change in the world or may do so in the future. The activities are organized under the four big debatable questions you see above, and you may notice that they are relevant to questions from other global contexts, too. The activities will require you to apply understanding from earlier in this book in new ways and to make connections between the sciences we have explored. They may also provide you with opportunities to apply understanding from other MYP subjects you study, and the new understanding you make will help you to see those other MYP subjects in a different light.

Many of the activities have an action element and will provide a springboard for service learning opportunities that take your MYP Integrated Sciences programme out of the laboratory and into the real world, to make a difference.

How will we make the world of the future?

ACTIVITY: Developing materials of the future

ATL

- Information literacy skills: Create references and citations, use footnotes/endnotes and construct a bibliography according to recognized conventions; Evaluate and select information sources and digital tools based on their appropriateness to specific tasks; Present information in a variety of formats and platforms; Access information to be informed and inform others
- Media literacy skills: Locate, organize, analyse, evaluate, synthesize and ethically use information from a variety of sources and media (including digital social media and online networks); Seek a range of perspectives from multiple and varied sources
- Communication skills: Use appropriate forms of writing for different purposes and audiences; Give and receive meaningful feedback; Negotiate ideas and knowledge with peers and teachers

The different types of materials that exist come down to the way that atoms are bonded to each other. Materials science is a branch of study which focuses on discovering and designing new materials, to offer solutions to scientific problems.

In this activity, you will work in pairs to take on the role of scientists who have discovered a new technology. You will compete against the other scientists in order to obtain additional funding for your technology. All of the scientists will be presenting at the annual 'Cash for a stake' competition, where a group of investors listen to the presentations and, if they like the idea, provide the financial investment needed to create that product in return for a stake in the company.

Your task is to prepare a 'pitch' presentation for one of the projects in the list that follows. When all of the groups have pitched, each will vote on how to spend the budget of US$1 000 000 available; it can all be allocated to one group for a single material technology or it can be divided up (evenly or unevenly) between different groups or technologies.

The technologies you can choose from are listed here. Ensure that each of the topics is covered by at least one group in the class.

- **A colour-changing graphene skin**
- **A graphene sieve**
- **3D printed ovaries for mice**
- **Electronic skin patches**
- **A soft-growing robot**

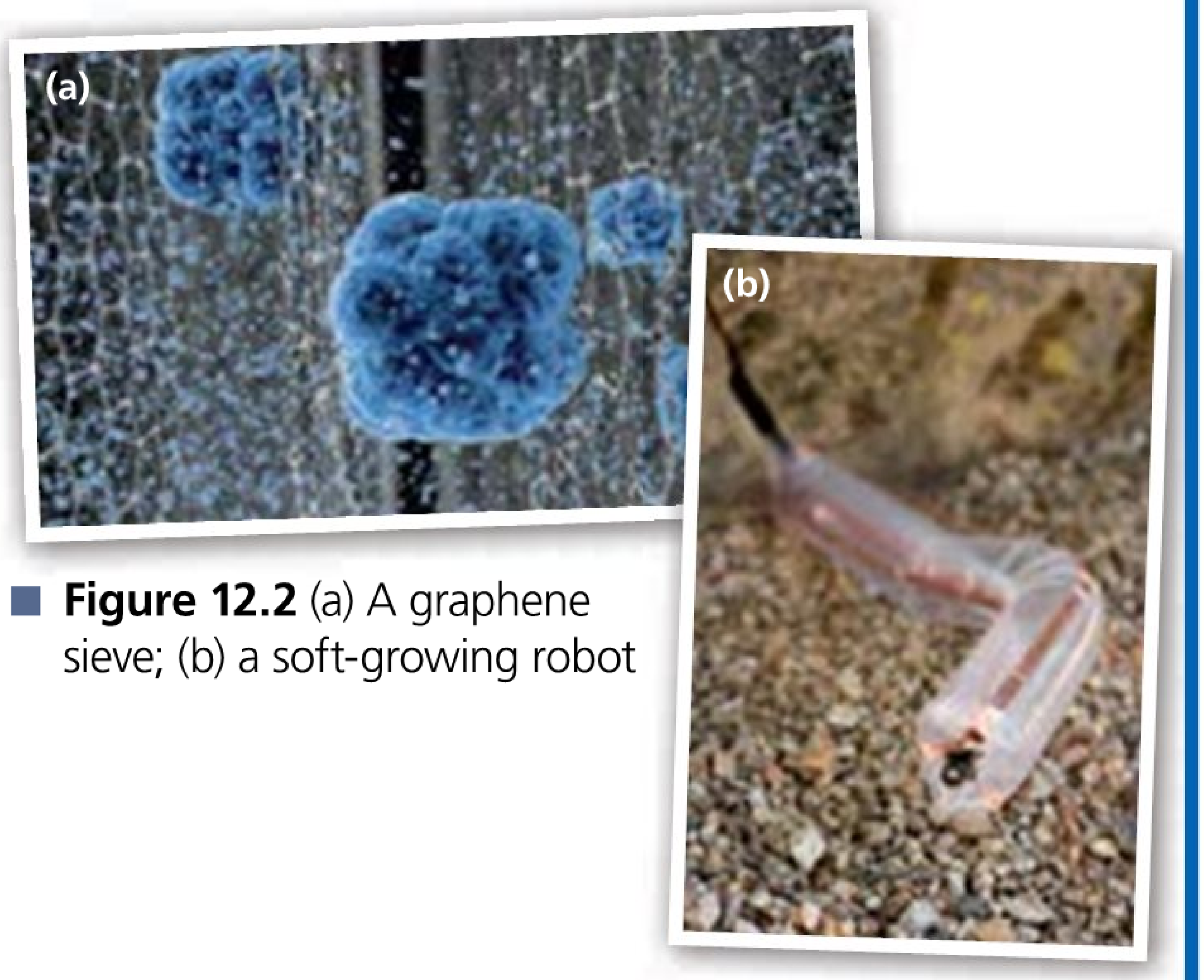


Figure 12.2 (a) A graphene sieve; (b) a soft-growing robot

When preparing your presentation, make sure to include:

- **what local or global problem the material is capable of solving, how it works and how it can be used**
  - **make sure you emphasize why your product should be invested in and what makes it so important and different to others**
- **an evaluation of the material, to include a discussion of its benefits and limitations, making links to two world factors**
- **scientific language but with any key terms explained as the investors are not necessarily experts in the field of science**
- **a fully documented bibliography, so that the investors can find out more about the subject if they wish.**

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

CAN WE ENGINEER OUR OWN BODIES?

ACTIVITY: Order an organ!

ATL

- Communication skills: Write for different purposes
- Information literacy skills: Make connections between various sources of information
- Critical-thinking skills: Gather and organize relevant information to formulate an argument
- Media literacy skills: Locate, organize, analyse, evaluate, synthesize and ethically use information from a variety of sources and media (including digital social media and online networks)
- Reflection skills: Focus on the process of creating by imitating the work of others

Scientific innovations and developments have opened the door to fascinating research that could revolutionize the future of regenerative medicine and lead to the creation of living human organs in the laboratory, bypassing the need for donors. Read this article to orientate yourself in the current research:
www.nature.com/articles/522373a

■ **Figure 12.3** An artificial ear grown *in vitro*

You are a university researcher about to start your own laboratory in the school of Biomedical Sciences and you are given the option to choose a project to work on. You are interested in tissue engineering and bioprinting and you want to write a grant proposal asking for funding from a funding organization. You are asked to write a scientific report, supported by evidence, suggesting what kind of research will be carried out and emphasizing that this is a leading field that will result in exciting research which will be published in scientific journals.

To **evaluate** the collected evidence you will need to:

- **explain** the ways science is applied and used to address the problem of needing organs and the dependence on donors
- **discuss** and **evaluate** evidence published on bioprinting and tissue engineering and reflect on the impact of these scientific developments on the health sector
- **suggest** some potential research themes that will be carried out in your future laboratory
- make sure you **apply** scientific language and use data when communicating your ideas
- make sure your information is clear and concise
- include a reference list of all the sources you used.

Hint

Use the referencing option which is integrated in the word processing program that you are using by adding your references to a library created on the program.

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

IS PLASTIC STILL THE ANSWER?

Take action: Plastics here, plastics there, plastics everywhere …

ATL

- Information literacy skills: Process data and report results
- Critical-thinking skills: Practise observing carefully in order to recognize problems; Gather and organize relevant information to formulate an argument; Draw reasonable conclusions and generalizations

! In *MYP Sciences by Concept 3:* Chapter 2 you were introduced to the term polymer. Review and research polymers before you begin this activity.

! Your teacher may demonstrate the 'nylon rope trick' in which you can see a polymer nylon chain form before your very eyes. Alternatively, you can watch a video of the reaction here: **www.youtube.com/watch?v=bNh5hK2f6TM**

1 **Copy and complete a table like Table 12.1 to find out about different types of plastics and their use. List the following plastics in the first column:**
- Polyester
- Polypropylene (PP)
- Polystyrene (PS)
- Polytetrafluoroethylene (PTFE)
- Nylon
- Low-density polyethene (LDPE) – this is still sometimes referred to as polyethylene
- High-density polyethene (HDPE) – this is still sometimes referred to as polyethylene.

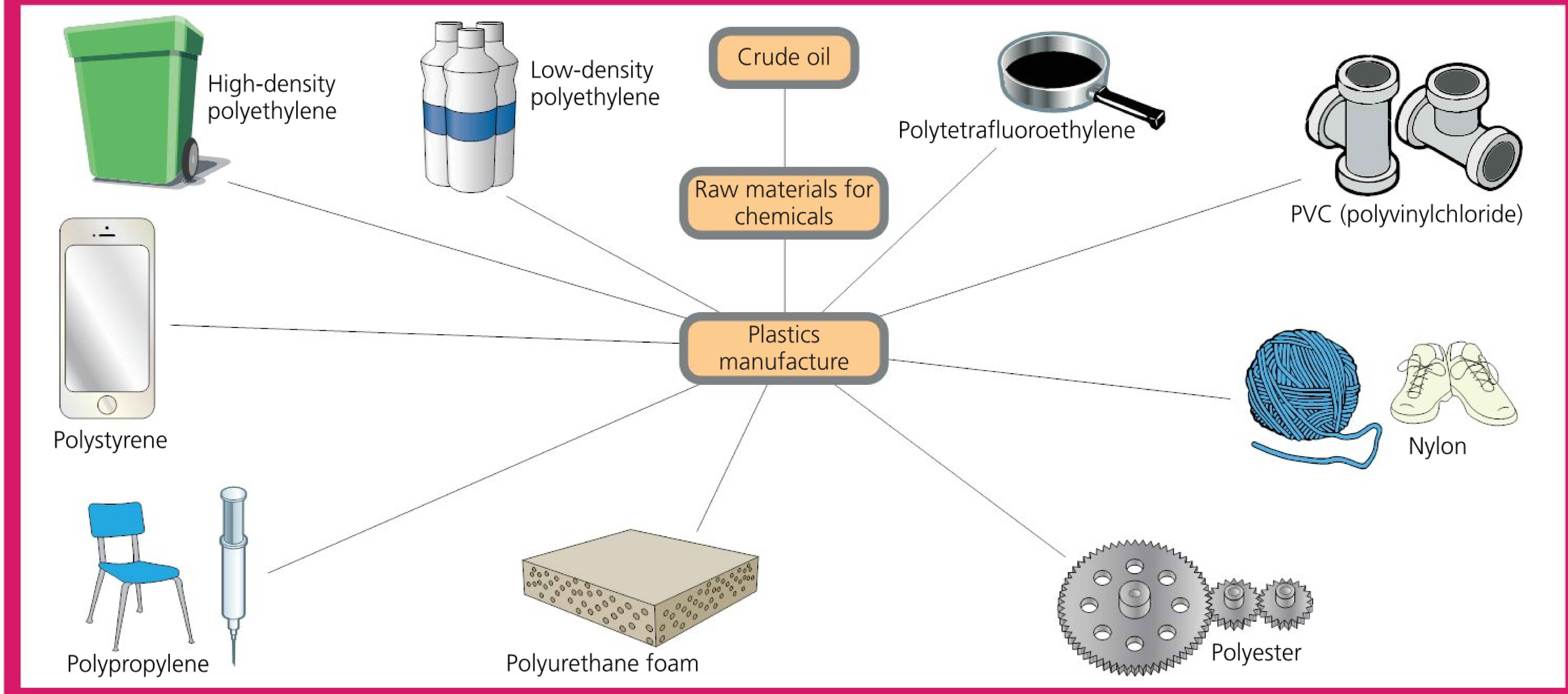


Figure 12.4 Plastics here, plastics there, plastics everywhere

Name of plastic	Description of properties of plastic	What is the plastic used to make?	Recycled use of plastic
Polyester			

Table 12.1 What, where and why?

2 Did you know that all types of plastic can be recycled? Find out what they can be recycled into at the end of their lifetime.

Hint

To help you complete the final column of the table, search for what the plastic recycling symbols mean.

3 You may be starting to realize that a vast number of objects you use in your everyday life are made of these different types of plastic. A lot of these can be traced back to crude oil.

a Carry out a plastic audit of your lifestyle. Every time you use a plastic object, make a note of it and what type of plastic it is. If the object doesn't say, make an educated guess or do some research.

b If you discard the object after its use, make a note of whether it is recycled or placed with the normal rubbish.

c Organize your audit results in a table that shows clearly the different types of plastic and the number of objects of each type of plastic used.

d Calculate the percentage of each type of plastic used in a final column.

e Add an additional column and calculate the percentage of each type of plastic recycled.

Hint

For part (e), this should be a ratio of the number of objects recycled to the number of objects discarded, not the number of objects used, as some objects will be reused. Your original survey should have this information.

f Present a graph/chart for the percentage of each type of plastic used. Display the percentage of the plastic recycled in the same graph.

4 Create a short questionnaire to find out more about the types of plastics other students in your school use, both at home and at school. Find out about what students know about the recycling of plastics and whether students recycle their plastics.

Hint

Other students might not be familiar with the scientific names of the different plastics so make sure your questions are written in a way that they can answer them; for example, you might want to ask about plastic bags rather than LDPE.

For more information about how to create your questionnaire, refer to the box on *Questionnaires* which follows.

5 Carry out some **research** about incineration and landfill; this is where plastics that are not recycled end up.

6 Now write a report with your findings. In your report **explain** the types of materials that are made from plastics and give examples of how they make our lives easier. **Explain** how you carried out your plastic audit, **analyse** your data and **summarize** which plastics are used the most and the types of products that they are found in. **Summarize** the degree to which recycling occurs. **Discuss** the impacts of sending plastics to landfill or incinerators, **explaining** what these processes are and making specific reference to the environmental impacts of these processes. In your conclusion **suggest** how students could be better informed of the consequences of their choices and come up with a plan to improve the use and disposal of plastics. Provide a list of fully documented sources with your report.

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

Questionnaires

Questionnaires are a list of questions that are used to gather information that may not otherwise be available. The type of questions that you use in a questionnaire can vary. Some examples of the types of questions you can ask are:

- A question with a yes or no answer – This is called a dichotomous question, for example 'Do you use plastic objects?' These are simple to answer and can be transformed easily to a statistic or graphical form.
- Multiple choice questions – Here the answers are provided as tick boxes so the person completing the questionnaire has to decide which of the options provided best represents him/her. Sometimes more than one option can be selected. One of the difficulties with this is that when you are designing the answers, you need to make sure you cover all possible answers, or include an option called 'Other'. For example 'Which types of plastics do you use in your everyday life?'
  - LDPE ☐
  - HDPE ☐
  - Nylon ☐
  - PP ☐
  - PTFE ☐
  - Other ☐
- One word answer – If it is hard to predict all possible answers, you could ask a question that requires a one-word answer response. For example 'List the type of plastic that you use the most.'
- Opinion questions – If you want to find out about people's opinions, there are a number of ways you could do this.
  - You could request that the options provided are ranked. For example, 'Based on what you know about plastics, rank the following in order in terms of use, using a 1 for the type of plastic used the most and a 3 next to the type of plastic used the least.'
    - HDPE
    - Nylon
    - PP
  - You could use a scale through which the options are ranked. For example, 'Decide which of the following categories best describes how often you use the different types of plastics: Not at all, Rarely, Sometimes, Usually, Regularly.' (See Figure 12.5.)
  - You could ask an open-ended question that requires a response in the form of a sentence. This makes the data harder to process, however, and can be quite time consuming.

These are some of the main types of questions that you could include in your questionnaire. If you would like to find out more about this topic, look up **types of questionnaire questions**.

Which of the following categories best describes how often you use the different types of plastics?

	Not at all	Rarely	Sometimes	Usually	Regularly
Plastic usage	○	○	○	○	○

■ **Figure 12.5**

WHAT ARE CLEVER MATERIALS?

! Take action: Blinded by the Sun? Redox and real life

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument; Develop contrary or opposing arguments
- Information literacy skills: Access information to be informed and inform others; Make connections between various sources of information; Present information in a variety of formats and platforms

! In this activity you are going to **explore** how redox reactions are responsible for the colour changes in photochromic lenses. Your role is that of the science editor for your school newspaper and one of your writers has included a link to a website that explains how photochromic lenses work. When you checked the website, you found it useful, but did not feel that it explained the science behind the redox reactions at a level that is suitable for your audience. You have decided to address this issue by **creating** your own article.

Figure 12.6 Glasses with photochromic lenses

! Start by reading through the original website to gain an overview of how photochromic lenses work and their history: **www.explainthatstuff.com/photochromiclenses.html**

! Carry out further research on the benefits and limitations of photochromic lenses, considering any economic or social implications their use may have.

! Take an A3 sheet of paper; this is an enlarged version of your final article. All of the information that you need to include must be on one side of this sheet (this includes images and citations). **Design** your article making sure there are sections on the following:

- an **explanation** of the problem photochromic lenses aim to solve
- an **explanation** of the science behind how the lenses work; this should include redox equations and explanations of any key scientific terms that you use, especially those that your readers might not be familiar with
- a **discussion** of the advantages and disadvantages of the lenses, including any social or economic implications their use may have. You need to conclude with an overall **evaluation** of the lenses.

! Before you start working on the A3 sheet of paper, consider what features your article should have in order to get the attention of your readers. You will also be assessed on the way you present your article, as well as how well the information is communicated. You must include all of your sources; these can be submitted on a separate piece of paper or on the back of your A3 paper.

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

To what extent have scientists learnt from nature?

■ **Figure 12.8** This Spiderman toy weighing 40 g has been stuck to a glass ceiling by a 0.5 cm^2 piece of 'gecko tape' on its hand

■ **Figure 12.7** The gecko's foot has special adaptations that allow it to climb on surfaces

SEE–THINK–WONDER

Look at the gecko in Figure 12.7. What do you **see** in the picture? What do you **think** is happening? What does this make you **wonder**?

Biomimetics is a new field in which engineering, chemistry, physics, design and biology work together to come up with new technologies that mimic (imitate) nature. Scientists try to learn from nature's ways of solving problems for innovation and for improving existing machines, man-made processes and products. This is not new: from Leonardo da Vinci (see Chapter 1) to the Wright brothers, we have learnt from nature. However, modern biomimetics looks at the nanoscale to learn from the successful adaptations that living organisms developed over time through evolution and natural selection (Figure 12.7).

One of the many examples of how scientists are learning from nature is the study of the ability of lizards and geckos to climb on various surfaces in all directions without leaving residues. Scientists have been fascinated by the secret behind this adaptation for decades and have been trying to create materials with similar structures or properties. In 2003, Andre Geim and his team at the University of Manchester created 'gecko tape', a material that has a similar structure to the toe pads of geckos and lizards (Figure 12.7). Cutting edge nanotechnology processes were used in order to recreate the millions of tiny hairy structures that are partially responsible for the ability of geckos to climb on almost any surface. However, the manufacturing process proved too costly for making it on a scale that can be commercialized.

Up to 2004, it was thought that **van der Waals' forces** exerted by the microscopic hairs on gecko feet were predominantly responsible for their adhesive properties. However, this was not enough to explain how the gecko released its hold from the surface. In 2012, scientists Duncan Irschick and Alfred Crosby, and their team from the University of Massachusetts Amherst, published their invention: Geckskin™. Geckskin is a reusable adhesive material that can be made from any type of material and can stick strongly to a wide range of surfaces such as metal, wood and glass. In their study of the gecko's climbing properties, they looked at all the structures and mechanisms involved, not just the tiny hairs on the toe pads. The other interesting feature is the use of renewable, reusable resources that make their invention sustainable.

For more on gecko tape and Geckskin watch these videos:

www.youtube.com/watch?v=uC2VShczjrg

www.youtube.com/watch?v=9ZJYbcG0Ts0

and search online using the terms **Geckskin, gecko tape**.

Active watching

Exploring videos about a topic of interest enables you to broaden your sources of information and may help you grasp some concepts and points of view better. However, the ability to take notes effectively while watching is a skill that may need some practice. There are a number of strategies that could help you master this skill to become an 'active watcher' rather than a passive one. One is by using some sort of organizer or a table in which you include three columns; for example, one for the key concepts or ideas being discussed, another for short notes or keywords on what was discussed and a third one where you record the time at which the information was shown so that you could go back and view it again.

Another method is by using mind maps or branching diagrams where you record information that branches from another set of facts or ideas. You could also use abbreviations instead of writing whole words such as 'mitchond' instead of 'mitochondria', and write symbols for scientific names such as Ca instead of calcium. It might be helpful to watch the video once quickly without taking notes just to find out what ideas and concepts are being discussed then watch again after preparing a way to organize your notes.

! Take action: Mimicking nature has just become more interesting

ATL

- Communication skills: Use a variety of speaking techniques to communicate with a variety of audiences; Read a variety of sources for information and for pleasure
- Media literacy skills: Communicate information and ideas effectively to multiple audiences using a variety of media and formats
- Collaboration skills: Listen actively to other perspectives and ideas
- Information literacy skills: Access information to be informed and inform others; Understand and implement intellectual property rights

! You have been asked to study and **present** the work of a biomimetics research team of your choice to your school community. You must focus on one specific aspect of nature (an animal, a plant, a special material or molecule). The aim is to inspire students who have special interests in science, technology, design and engineering as well as to inform others about these new inventions.

! You will work in pairs to prepare a poster that you will **present** in a mini poster conference with other groups in your class. Your audience will be teachers, students from all ages, parents and other school staff. In order to reach all sections of the school community, use a form of digital media to show videos or short films about the invention.

! Watch these videos to become more familiar with biomimetics and its aims and applications:

www.youtube.com/watch?v=XiGrPBEsJ60

www.youtube.com/watch?v=UHb_XNgIHFY

www.youtube.com/watch?v=2d1VrCvdzbY

! Search **biomimetics, breakthrough, new, inventions, applications** to find examples of the latest applications. In order to show the potential of your chosen invention/application to your audience, your poster must:

- **Describe** and **explain** the science behind the invention; what biological properties have been studied or used as an inspiration for this invention or new technology? How have these properties been mimicked? What solutions does this product offer?
- **Discuss** the social/economic/environmental/political/ethical implications of this new invention.
- **Apply** scientific language and terminology and show diagrams and illustrations to help your audience understand the concepts covered. Remember your target audience and be prepared to answer questions from various members of the school community.
- **Document** all of the sources using a recognized referencing and citation system.

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

How will we meet the energy demands of the future?

HOW CAN WE REDUCE OUR ENERGY USE?

Take action: Saving the world one switch at a time

- In Chapters 5 and 8 we explored electrical energy and the ways in which it can be used efficiently. In many parts of the world, the environmental impact of any appliance or even whole homes must be reported to the buyer by law (Figure 12.9).
- Electrical power consumption is a major expenditure for most households.
- **Research** and find one way in which our power consumption can be reduced. **Explain** how the power will be saved using science you have learnt.
- **Estimate** how much power you could save, and how much money you could save, if your parents adopted this method of reducing power consumption.
- Write a report for your parents. **Present** your findings in tables, charts and graphs that will **explain** to them how much energy you are using. In your report, **evaluate** the impact on their daily lives of making these changes and **compare** to the benefits the reduction in consumption would bring.
- Here are some websites that you might find helpful:

  www.energysavingtrust.org.uk/

  http://hes.lbl.gov/

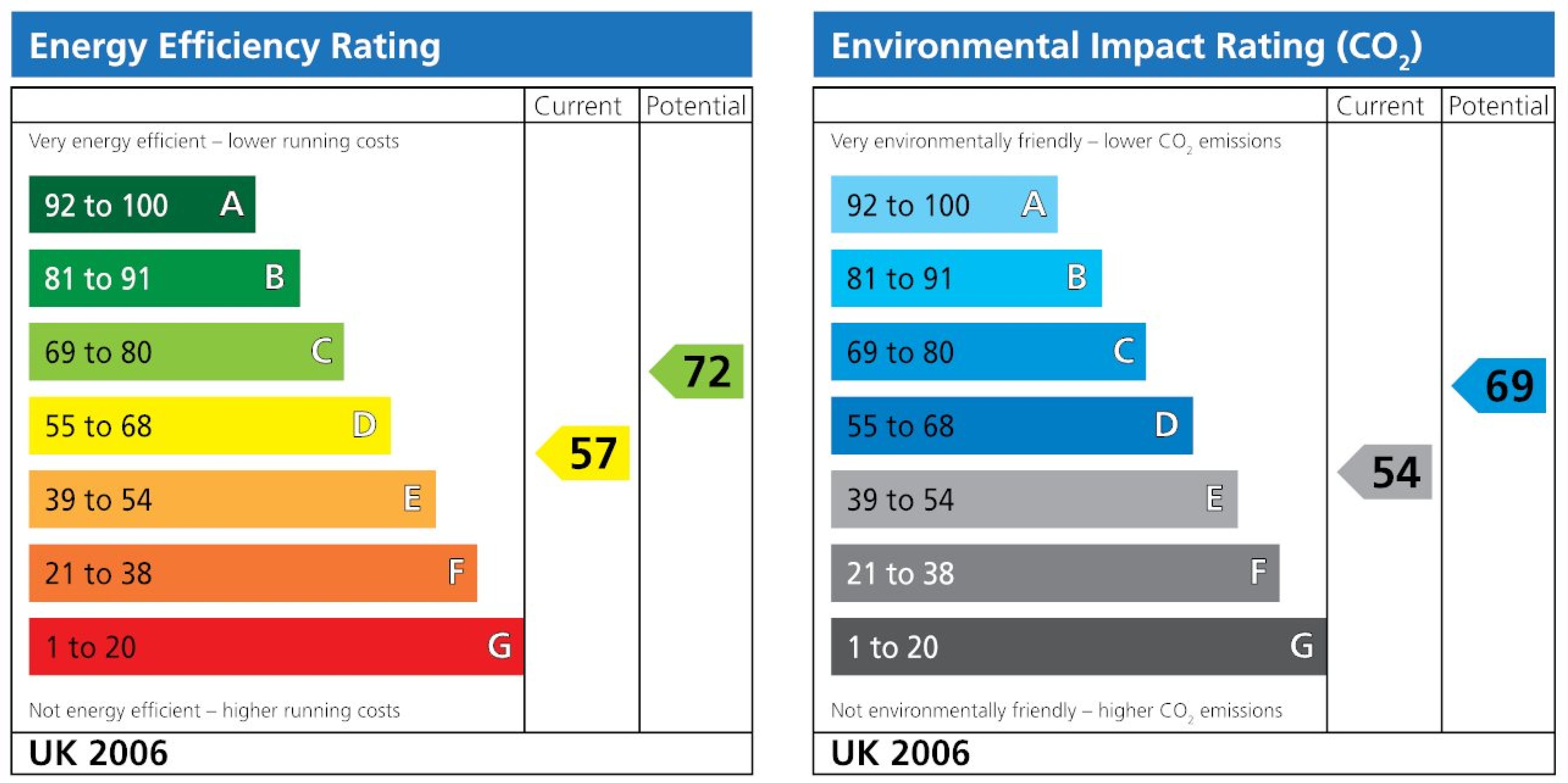
  www.aceee.org/consumerguide/

  www2.ademe.fr/servlet/getDoc?id=11433&m=3&cid=96 (in French)

  www.idae.es/index.php/lang.es (in Spanish)

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.



The energy efficiency rating is a measure of the overall efficiency of a home. The higher the rating, the more energy efficient the home is and the lower the fuel bills will be.

The environmental impact rating is a measure of a home's impact on the environment in terms of carbon dioxide emissions. The higher the rating, the less impact it has on the environment.

■ **Figure 12.9** Two environmental impact ratings for a home in the United Kingdom

ACTIVITY: Nuclear power – yes please or no thanks?

ATL

- Communication skills: Read critically and for comprehension; Write for different purposes; Share ideas with multiple audiences using a variety of digital environments and media
- Collaboration skills: Work collaboratively in teams; Build consensus
- Media literacy skills: Seek a range of perspectives from multiple and varied sources
- Critical-thinking skills: Evaluate evidence and arguments; Consider ideas from multiple perspectives

In Chapter 9 we explored radioactive materials and in Chapter 11 we looked at the responsibility held by scientists who used their understanding of radioactivity and the nucleus to devise nuclear weapons. Nuclear power production by **fission** is a peaceful use of our understanding of the atom's nucleus.

While nuclear power has become well established in the last 50 years, it remains controversial with many environmental campaigners speaking out against it.

On your own read Sources A and B.

Source A

Read the following article from a British national newspaper in 2009: **https://uk.reuters.com/article/uk-britain-nuclear/go-ahead-given-for-new-nuclear-power-plants-idUKKUA04916520080110**

Source B

Read the online blog by pro-nuclear environmental campaigner Mark Lynas: **www.marklynas.org/2012/06/friends-of-the-earth-considers-abandoning-anti-nuclear-stance/**

In pairs, **summarize** the main arguments represented in the articles.

Now research the arguments for and against nuclear power using the following search term: **nuclear power issues**. One person can research arguments for, the other arguments against nuclear power.

Share your research with your partner. Try to decide what your own opinion is on the issue.

Write the script for an online documentary about the nuclear power issue. Include a summary of the physics of nuclear power. Try to represent both sides of the debate equally and **outline** arguments that are environmental, economic and social. At the end of the documentary **outline** your own opinion and **summarize** the arguments that support it.

Why not actually make your documentary? You can use a laptop/tablet or any other gadget with a built-in webcam. If you are good at using video editing software, you can include your own charts and diagrams.

Share your documentaries with the class, or even in a school assembly or town meeting!

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

HOW CAN WE USE ELECTRICITY-GENERATING ORGANISMS TO OUR BENEFIT?

! Take action: Which electricity-generating organisms are the future?

ATL

- Collaboration skills: Delegate and share responsibility for decision-making; Help others to succeed; Take responsibility for one's own actions; Listen actively to other perspectives and ideas; Encourage others to contribute
- Communication skills: Use appropriate forms of writing for different purposes and audiences; Read a variety of sources for information and for pleasure; Make inferences and draw conclusions; Write for different purposes; Paraphrase accurately and concisely; Preview and skim texts to build understanding

! You are the science editor of a global newspaper and are writing an article on the use of electricity-generating organisms. Your task is to research one of the suggested options and **create** a newspaper article assessing its potential as a viable technology now or in the future. Your article should have a catchy heading to get readers' attention and should be written in an appropriate format, taking the language and appearance of a newspaper article into account.

! Watch the following video to introduce you to the concept of bioluminescence, on which all of the examples are based, and find out more about where we see it in nature: **https://oceantoday.noaa.gov/bioluminescentocean/**

! Read through the suggested topics and decide as a group which one you will focus on. Use the guidance points to structure your research, considering how best to divide up the work within your group and defining clearly the outcomes for each of your roles.

- *Can bioluminescent bacteria be used to detect landmines?* Search for **bioluminescent bacteria in landmines** to start your research.
- *Can* E. coli *bacteria be used to create trees that are streetlamps?* Search for **we could grow our own fairy lights** to start your research.
- *Can bioluminescent bacteria help doctors scan organs and make better diagnoses?* Search for **deep sea creatures shed light on the future of medical engineering** to start your research.
- *Can bioluminescent bacteria detect water pollution?* Search for **illuminating the perils of pollution, nature's way** to start your research.
- *Can jellyfish genes create glowing potatoes that tell us when they need water?* Search for **jellyfish for fluorescent potatoes** to start your research.
- *Can fireflies save the life of soldiers?* Search for **military eyes glowing secret of fireflies** to start your research.

! In order to assess the potential as a viable technology at present or in the future, your article should include:

- what issue your technology is trying to solve
- the science behind bioluminescence; use **http://ocean.si.edu/bioluminescence** as a starting point
- what has been achieved so far
- the advantages and disadvantages of the technology making links to any of the world factors
- a conclusion of whether you think it is a viable technology or will be in the future
- a full bibliography of your citations. Remember to consider the reliability of the sources you find.

! Share your final articles as a class to find out more about these unconventional technologies.

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

How can we live in balance with the natural world?

Links to: Design

In the activity below, technology, science and design are working together to make efficient urban farms. Design helps to create solutions to issues related to factors affecting plant growth.

Take action: Design a sustainable school community

ATL

- Communication skills: Use a variety of media to communicate with a range of audiences; Negotiate ideas and knowledge with peers and teachers; Organize and depict information logically
- Collaboration skills: Delegate and share responsibility for decision-making; Listen actively to other perspectives and ideas; Encourage others to contribute

! In Chapter 11 you learnt about some of the greatest issues facing mankind: pollution, climate change and the depletion of the ozone layer. In this activity you will work in groups to **design** a hypothetical sustainable school community, trying to minimize negative impacts on the environment.

! Start by watching this video for inspiration: **www.youtube.com/watch?v=_s9dxc_jVlY&feature=related**

! Divide yourselves into groups of three or four and consider all of the aspects of your school community that may have impacts on the environment. Consider the transport methods of staff and students to and from school, the energy needs of the school, the food provided, the materials used and processes such as recycling that occur.

! Your task is to **create** a presentation for your school principal, with recommendations of changes that could be implemented in order to create a more sustainable community. Your presentation should include:

- the recommended actions and an **explanation** as to how each of these will address a specific problem or issue
- a **discussion** and an **evaluation** of the implication of introducing each of the recommended actions and how these interact with a world factor.

! Your presentation should include appropriate scientific terminology to aid the understanding of the key issues. You should also submit a bibliography with fully **documented** sources separately.

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

ACTIVITY: Are urban farms the solution?

ATL

- Communication skills: Structure information in summaries, essays and reports
- Transfer skills: Make connections between subject groups and disciplines

Watch this video to get you started in thinking about urban farming: **www.youtube.com/watch?v=aCFTL5s_Lq8**

Task

You have been asked to write an article in which you **evaluate** the potential that urban farms have to solve world food-related issues.

Search **vertical, pink, plants, LED, farming, breakthrough** to find one or more source about this topic.

In your own article, you must:

- **describe** and **explain** the science used to grow plants in urban/pink farms, focusing on the concept of limiting factors
- **describe** the way these farms are designed to maximize yield
- **discuss** and **evaluate** the implications of using urban farms on the economy, the environment or society
- **apply** scientific language and use statistical facts
- **document** all of the sources using a recognized referencing and citation system.

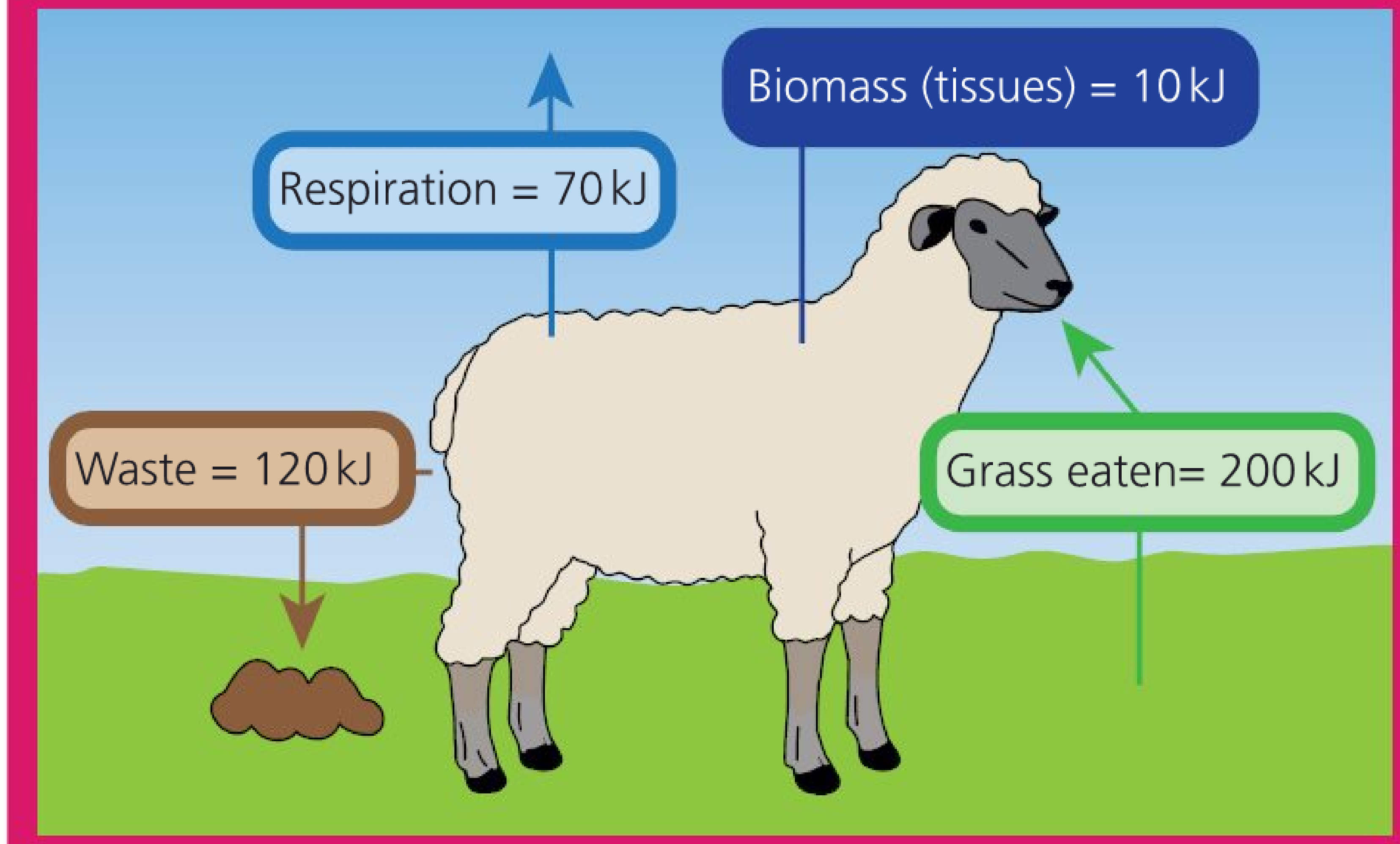
Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

! Take action: How do we help nature save energy for our benefit?

ATL

- Communication skills: Negotiate ideas and knowledge with peers and teachers
- Critical-thinking skills: Evaluate and manage risk; Propose and evaluate a variety of solutions
- Information literacy skills: Access information to be informed and inform others



■ **Figure 12.10** An example of energy efficiency in a sheep

! Work in groups of four students and **analyse** the information available in Figure 12.10 as an example of how energy is used in a herbivore.

1 **Calculate the percentage of energy lost in waste. Discuss whether or not you think the process is efficient in this example.**
2 **State the percentage lost in respiration and metabolism.**
3 **Explain how you would make this sheep more efficient so that it produces more biomass from the same amount of grass.**

Task

! You are a group of agricultural engineers working for the government department of agriculture in a less economically developed country. You have been sent to help four farmers who are struggling to meet the costs of their farms. The population in their village and surrounding villages is growing and their products will soon not be able to meet the increasing demand. These farmers are still following traditional farming methods and each specializes in a particular crop or **livestock**.

Farmer 1: Grows tomatoes

Farmer 2: Grows lettuce

Farmer 3: Raises cows for milk production

Farmer 4: Raises cows for meat production

! Each student must choose one farmer to work with, then as a group you can share and **discuss** your ideas. Your task is to offer expert advice to these farmers based on new methods following the latest research and developments in the field of agriculture and intensive farming.

! You might want to search: **intensive farming, yield increase, methods, sustainable farming, sustainable agriculture** to help you in your research.

! After completing your research, you must write a small proposal that you will present to the farmers (your classmates) and to the department of agriculture. Once approved by the authorities (your teacher), your proposal might secure some funds for the farmers to help them in modernizing their farming methods. In this proposal, you must:

- **Describe** and **explain** the science behind the new methods you are proposing and how they will help to solve the problem(s) you identified.
- **Discuss** and **evaluate** the implications of the solutions you are proposing on the cost of farming, the immediate and global environment, the welfare of the animals in the farm, the ethical implications of such methods and the effect on the life of the people in the village and the neighbouring villages. (You may choose to focus on one factor in detail or summarize the link with all of the factors.)
- **Apply** scientific language and use statistical facts and information and illustrations to support your argument.
- **Document** all of the sources using a recognized referencing and citation system.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion A: Knowing and understanding.
- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

To what extent can we learn from natural systems to harness energy sustainably?

! Take action: Design a plant-inspired solar panel

ATL

- Creative-thinking skills: Design new machines, media and technologies
- Communication skills: Negotiate ideas and knowledge with peers and teachers
- Critical-thinking skills: Evaluate and manage risk; Propose and evaluate a variety of solutions

! Many plants have adapted their structures to maximize how much of the Sun's energy they capture and use to make organic molecules (see Chapter 5). Other plants, such as sunflowers, actually follow the Sun as it moves across the sky.

■ **Figure 12.11** What makes sunflowers a good inspiration for solar panels?

! While plants transform the Sun's energy into chemical energy, solar panels turn solar energy into electrical energy. Many scientists and engineers are trying to understand how plants maximize their use of the Sun's energy to inspire their design of solar panels in a quest for a greener future for our planet. Watch this video as an example:
www.youtube.com/watch?v=btdX8QdbyRQ

! Currently, the greatest efficiency in commercial solar panels is 21.5 per cent. In this activity, you will try to answer the question: *How can we be inspired by plants to better harness solar energy?*

! Work in pairs or groups of three. You work in a team of designers and electrical engineers in a solar panel manufacturing company. Your task is to **design** a prototype for a solar panel for domestic use that is inspired by plants' ability to maximize solar energy usage. Your target users could be home owners or even transportation manufacturers.

- Before you start, you must first find out how **photovoltaic solar panels** work. **Decide** on your target user to inform your choice of size and shape.
- **Apply** your knowledge and understanding about the process of photosynthesis and efficiency to inform your decisions.
- Once you finish your design, prepare a poster or a slide show to **explain** the science behind your design to the rest of the class. **Describe** the benefits that your design would have on the environment and on how we produce energy.
- You must **apply** scientific language and terminology and use diagrams to illustrate your ideas; remember to **document** all of the sources using a recognized referencing and citation system.
- **Evaluate** your design using feedback from your teacher and your classmates.
- Finally, consult with your design and science teachers to see if you could actually build your solar panel prototype!

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

To what extent should we modify natural processes to meet our needs?

■ **Figure 12.12** GM crops

ACTIVITY: The debate! Where do you stand on GMO?

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument; Evaluate evidence and arguments; Develop contrary or opposing arguments
- Creative-thinking skills: Practise flexible thinking – develop multiple opposing, contradictory and complementary arguments
- Communication skills: Negotiate ideas and knowledge with peers and teachers; Take effective notes in class; Make effective summary notes for studying; Find information for disciplinary and interdisciplinary inquiries, using a variety of media
- Reflection skills: Consider ethical, cultural and environmental implications

In Chapter 9 you explored some of the science behind genetic modification of organisms. Take a moment and think how you would answer the question: *Where do I stand now on genetically modified organisms (GMO)?* Write your answer on a piece of paper or post it on your class online learning platform. Your answer should state whether you are 'for' or 'against' GMO and should only include one argument that makes you say this.

You are attending a debate at the Model United Nations (MUN) where you will be **discussing** the advantages and disadvantages of GMO. Your arguments must be based on scientific evidence and reflect the impact of GMO on the environment, health and agriculture. Examples may include: **golden rice, Bt corn, sheep factor IX, insulin, edible plant vaccines, salt-tolerant plants, herbicide-resistant plants**.

Document your references. Your research should also reflect on the interpretation of media or on the general public understanding of these GMO, **discussing** any myths or biases.

EXTENSION

Here are some videos from the news that might help you in your research:

www.bbc.co.uk/news/av/science-environment-25889792/purple-tomatoes-could-gm-crop-be-food-of-the-future

www.bbc.co.uk/news/av/science-environment-24519926/is-it-wicked-to-oppose-gm-crops

www.bbc.co.uk/news/av/uk-politics-17147649/gm-foods-meacher-on-super-tomatoes-and-trampled-fields

www.bbc.co.uk/news/av/science-environment-22997768/gm-food-paterson-warns-uk-risks-being-left-behind

In class, **present** your findings. At the end of the activity, and after listening to the scientific arguments, ask yourself again: *Where do I stand now on GMO?*

◆ Assessment opportunities

- ◆ This activity can be assessed using Criterion D: Reflecting on the impacts of science.

How can we share the world fairly for all?

Take action: Campaigning for the fair distribution of natural resources

ATL

- Media literacy skills: Locate, organize, analyse, evaluate, synthesize and ethically use information from a variety of sources and media (including digital social media and online networks); Seek a range of perspectives from multiple and varied sources; Communicate information and ideas effectively to multiple audiences using a variety of media and formats
- Information literacy skills: Create references and citations, use footnotes/endnotes and construct a bibliography according to recognized conventions; Use critical-literacy skills to analyse and interpret media communications
- Reflection skills: Consider ethical, cultural and environmental implications
- Communication skills: Paraphrase accurately and concisely; Preview and skim texts to build understanding; Use a variety of media to communicate with a range of audiences

- The World Bank defines natural resources as 'materials that occur in nature and are essential or useful to humans, such as water, air, land, forests, fish and wildlife, topsoil and minerals'. Populations have always tended to settle in locations where natural resources were readily available because of their use as fuel, food, shelter and materials. Access to natural resources has also changed as technology has developed; Siberia, for example, has always had a wealth of resources but the remoteness of the locations has made access to this in the past limited.
- Natural resources are not evenly distributed across our Earth. The angle that the Sun strikes the Earth's surface varies across our planet, which has an effect on temperature and precipitation. Areas close to the equator experience much higher temperatures and higher levels of precipitation, with these two factors decreasing as you move further from the equator. This has an effect on the fertility of the soil, which facilitates the growing of crops and the ability to produce resources such as timber.
- The distribution of crude oil and natural gas across the globe varies. This has an effect on energy security, with countries that produce more energy than they need being energy secure and exporters of energy. How much energy a country is able to produce depends on how much is available as a natural resource, but also on whether the country has the financial means to exploit it.

DISCUSS

- What type of natural resources do we exploit? How have these changed in the last two centuries?
- A country that is rich in natural resources has the potential to use them or sell them in order to be used as a source of income.
- The World Bank has found that developing countries that do not have their own natural resources grow two to three times faster than countries rich in natural resources. A 2009 UNEP report *From Conflict to Peacebuilding: The Role of Natural Resources and the Environment* found that 40 per cent of civil wars over the past 60 years have been linked to natural resources and that since 1990 there have been at least 18 violent conflicts fuelled or financed by natural resources.
- One of the richest countries in natural resources is the Democratic Republic of Congo, but instead of benefiting from this, it was ranked one of the lowest on the United Nations Human Development Index in 2011 and 2012. The reason for this is the internal conflict around the extraction of natural resources, including metals that are used to make electronic devices. With the production of these devices constantly increasing, the problems surrounding these metals will continue to increase.
- In this activity, your class will **explore** a case study where the extraction of natural resources has led to internal conflict. You will work in pairs to raise awareness within your school community about the impacts of the uneven distribution of natural resources and how these can be exploited. The manner in which you raise awareness can take any form (talk, presentation, website or poster).

Take action: Campaigning for the fair distribution of natural resources *continued*

- Your awareness campaign should **outline** what the specific natural resources at the centre of the conflict are and **explain** why those particular substances are needed. You should **discuss** and **evaluate** the implications of the extraction and selling of the resources, considering both the benefits as well as the problems caused and making reference to how these interact with any relevant world factors. You should also **suggest** measures that can be taken to put an end to this. Make sure you **apply** scientific language consistently in order to communicate your points clearly. You will need to submit a fully **documented** list of citations for your research.

Figure 12.13 Some examples of natural resources

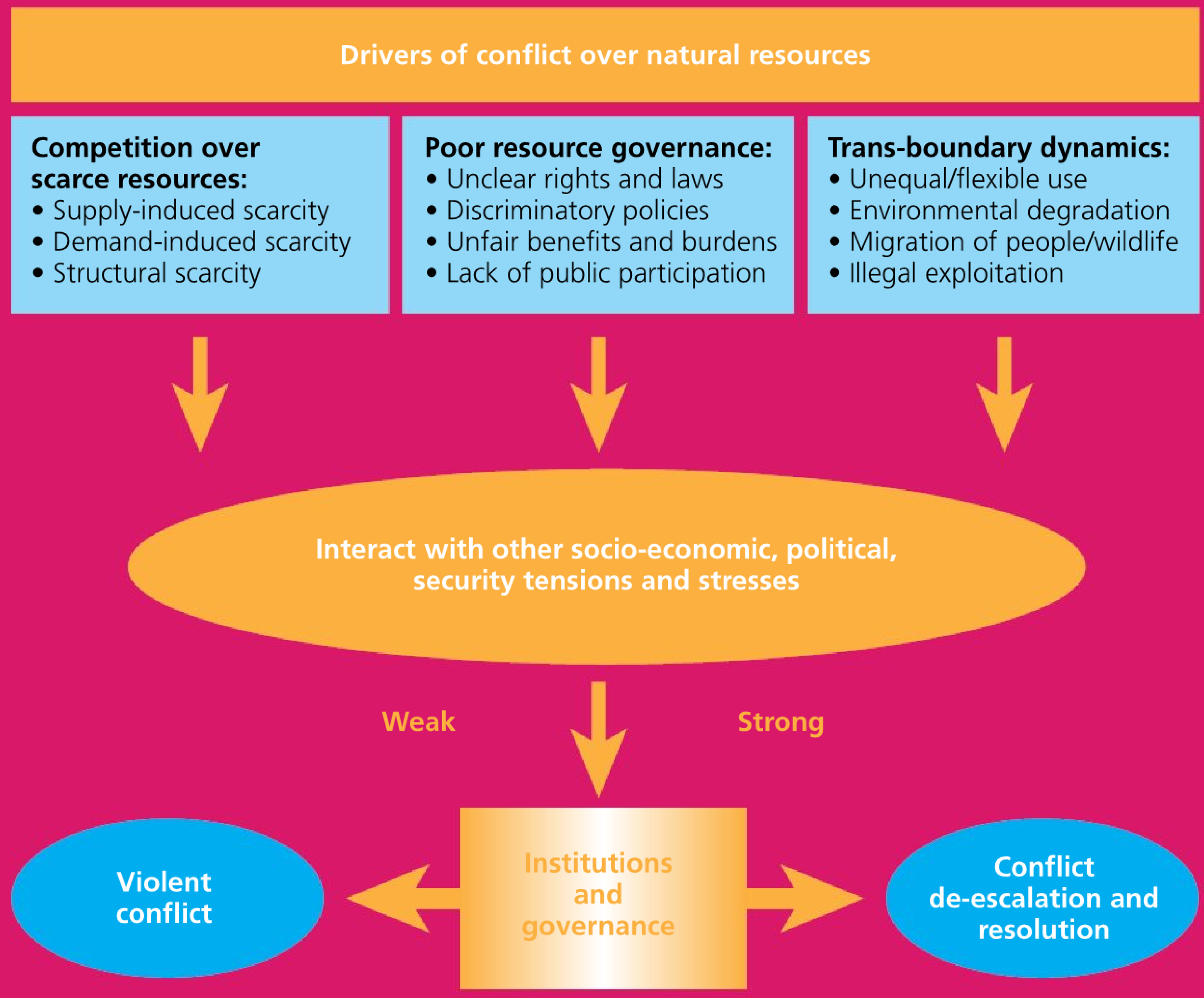


Figure 12.14 Conflicts over natural resources can drive, reinforce or compound other stress factors that can result in violent conflict

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

Links to: Individuals and societies

In Individuals and societies you may have learnt about imperialism, where countries used military force to increase a country's power, usually by colonizing other countries. This is also one way that industrialized nations have come to control many of the Earth's natural resources. Further, there are issues over the overexploitation of natural resources by the country itself for economic benefits as well as the role that politics plays in how the money generated from the sale of natural resources is used.

Take action: How could you help celiac disease sufferers in developing countries?

ATL

- Media literacy skills: Locate, organize, analyse, evaluate, synthesize and ethically use information from a variety of sources and media (including digital social media and online networks)
- Communication skills: Use a variety of media to communicate with a range of audiences
- Creative-thinking skills: Create novel solutions to authentic problems

! Search about celiac disease, its causes, symptoms, how it is diagnosed and treated. This disease touches one per cent of the world's population but the location where someone lives in the world could affect how their disease is managed as seen in Figure 12.15.

Task

! You are part of a group of scientists working for a charity organization that aims to help people with health issues in developing countries. Your task is to attempt to **solve** some of the issues related to celiac disease by taking one of the following actions.

! **Action 1:** Write a report to the health authorities in that country advising them about how to improve the diagnosis rates of celiac disease and how to inform and follow up with patients who have been diagnosed. (Studies show that large populations across the world seek unreliable sources of information about their condition once diagnosed, and need a better follow up by their health practitioner.)

! **Action 2:** Write a letter to the authorities concerned encouraging them to help celiac disease patients in accessing and overcoming the economical constraints associated with **gluten-free** products. (In some developed countries, celiac disease patients have monthly allowances or support with food prescriptions.)

! **Action 3: Design** an app that could help celiac disease sufferers to identify gluten-free foods and check for the presence of gluten in their food. There may be other apps already available so make sure that you search online for gluten free or gluten checker apps to inform your design and get inspired. Maybe you want to improve some existing apps to make them suitable for the population in the target country. You could **present** your app design in the form of a slide show or a small poster show in which you take the audience through all the sections of your app.

■ **Figure 12.15** Geography determines the kind of care a patient with celiac disease receives ➤

! Take action: How could you help celiac disease sufferers in developing countries? *continued*

! **Action 4:** Make an information leaflet to inform parents of young children affected by the condition about how to care for their children and make correct choices about their diet. (Studies show that being well informed about the gluten-free diet is a key factor in enabling children and their families to manage the condition successfully.)

! You could focus on one issue and action individually or you may look at them as a group together. Here are some ideas for developing your project:

- Plan to organize interviews with local doctors or health authorities if you live in a country that faces these issues. Link with students from those parts of the world through social media and ask them to fill in a survey for you.
- Consult national health and WHO statistics for that particular country. Use websites for help, such as: **www.gapminder.org/** or **www.ncbi.nlm.nih.gov**
- **Explain** how you used scientific information about celiac disease to design your product. What specific information do you want your target audience to know?
- **Describe** the solutions you are suggesting.
- **Discuss** and **evaluate** the implications of your action to solve the issue you chose to work on. What are the economic, cultural, social, ethical, moral and political factors you should consider when taking such action? What implications could your action have on these factors?
- Consistently **apply** scientific language to communicate your understanding and your recommendations.
- Correctly **document** your sources of information. Have you used reliable sources in your search?

Assessment opportunities

- This activity can be assessed using Criterion A: Knowing and understanding and Criterion D: Reflecting on the impacts of science.

! Take action: Do you know which of the foods you are eating are genetically modified?

ATL

- Collaboration skills: Build consensus
- Information literacy skills: Access information to be informed and inform others; Present information in a variety of formats and platforms
- Critical-thinking skills: Gather and organize relevant information to formulate an argument

! The World Health Organization (WHO) notes that GM foods offer cheaper and improved crops which are checked for safety and toxicity before approval. However, not many people know which foods are GM. As a class, discuss whether people should be given the right to know by labelling all GM food and ingredients.

1 **Conduct a survey to see how many people in your school (students and teachers) are aware of whether foods they are eating are GM and organise the data in a table.**

2 **Now, take action and design an information leaflet on the foods mentioned in the survey in addition to other GM foods that were unknown to them. Your leaflet should inform of any risks related to these GM foods and whether they are declared safe in all countries or banned in some.**

! Develop a traffic light system, *green* for no known risk, *yellow* for minimal risk and *red* for foods that are associated with risks or are banned in some countries.

! Your information for all foods needs to be specific, solely based on scientific evidence and well referenced.

! For the foods that you labelled yellow or red, you should suggest alternative foods with no risks.

Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

ACTIVITY: How well are we controlling our reproduction by contraception?

ATL

- Critical-thinking skills: Gather and organize relevant information to formulate an argument
- Information literacy skills: Collect and analyse data to identify solutions and make informed decisions; Process data and report results

There are many methods of contraception used by males or females to prevent sperm fertilizing eggs. The use of contraceptive methods varies in different countries in the world. According to the World Health Organization (WHO):

'Contraceptive use has increased in many parts of the world, especially in Asia and Latin America, but continues to be low in sub-Saharan Africa. Globally, use of modern contraception has risen slightly, from 54% in 1990 to 57.4% in 2015. Regionally, the proportion of women aged 15–49 reporting use of a modern contraceptive method has risen minimally or plateaued between 2008 and 2015. In Africa it went from 23.6% to 28.5%, in Asia it has risen slightly from 60.9% to 61.8%, and in Latin America and the Caribbean it has remained stable at 66.7%. Use of contraception by men makes up a relatively small subset of the above prevalence rates. The modern contraceptive methods for men are limited to male condoms and sterilization (vasectomy).'

Hint

You can access the complete page with more information on contraception at:
www.who.int/mediacentre/factsheets/fs351/en/

Interpret the text and extract data to **present** in a table then **plot** a suitable graph. What do you notice? Are there any patterns in the use of contraception across the world? Can you **explain** the results by linking them to the socio-economic state of these regions? Is contraception used equally by men and women? Has contraception use increased or decreased in different regions? How do the data relate to the timeline provided in the text?

Factors like varied success rates and ease of use of these methods means some are favoured over others. You can find information on different methods here:
www.who.int/mediacentre/factsheets/fs351/en/

Analyse the data and **discuss** what you think is the best choice supported with evidence from the data.

Fertility clinics are one way to inform people about contraception options. Plan a fertility clinic class play where you are a fertility health professional and you have different patients asking advice on their choice of contraception. Use the data to give clear advice to your patients suggesting suitable contraceptive methods while reflecting on the impact of these methods on their health. In your advice you should take into account their medical history, any undesirable effects, including any long-term effects on fertility, and methods that offer protection against sexually transmitted diseases. **Suggest** the method that is easily available to them and how they could access it. Note any questions that your patients ask and that you don't have an answer for then carry out research to answer them.

Assessment opportunities

- In this activity you have practised skills that are assessed using Criterion C: Processing and evaluating and Criterion D: Reflecting on the impacts of science.

Can countries put their needs aside to work together on global issues?

! Take action: The Free Rider Effect

ATL

- Transfer skills: Change the context of an inquiry to gain different perspectives; Make connections between subject groups and disciplines
- Creative-thinking skills: Use brainstorming and visual diagrams to generate new ideas and inquiries; Make guesses, ask 'what if' questions and generate testable hypotheses
- Reflection skills: Consider ethical, cultural and environmental implications

! In Chapter 11, we looked at how the *Montreal Protocol on Substances that Deplete the Ozone Layer*, which came into force on 1 January 1989, was a global effort responsible for putting an end to the emission of substances that deplete the ozone layer, allowing it to recover to its natural levels gradually. This has been described as one of the most successful examples of global cooperation, where countries of the world worked together to achieve a global solution to a global problem.

! Another successful example of unified action is the replacement of leaded petrol with unleaded petrol. Following the inclusion of tetraethyl lead (TEL) in petrol in the 1920s, the damage it caused to the environment and human health led to it being removed from petrol in the United States in 1973, with the European Union following in the 1980s and with a complete ban of leaded fuel in the USA in 1996 and in Europe by the end of the 1990s. Progress was slower in Africa and Asia; in 2017, there were still six countries in these regions that use leaded petrol (Algeria, Iraq, Yemen, Myanmar, North Korea and Afghanistan).

! But not all global endeavours have been this successful. The progress in combating climate change has not been as effective as it could have been. In the following activity you will be taking on the role of a scientific advisor to a national government, finding out more about the global effort to combat climate change and some of the consequences of not progressing in a unified way against one of the greatest threats to humanity.

! Read the following article to help you answer some of the questions:
http://unfccc.int/kyoto_protocol/items/2830.php

1 The Kyoto Protocol was introduced in an effort to work towards a solution for the global problem of climate change. Outline what it is. Explain how it was applied by addressing the following points:
   a State what the targets of each country were during the first and second commitment periods.
   b Under the protocol, countries must meet their targets through national measures. Suggest what some national measures could include.
   c Describe the three market-based Kyoto mechanisms in which a country could meet its targets, that are additional to national measures.

2 Discuss the benefits of the Kyoto Protocol, making specific reference to environmental and economic world factors.

3 The Kyoto Protocol was aimed at developed countries which were recognized as being responsible for the vast majority of emissions of greenhouse gases as their industries developed over the last 150 years. For this reason, countries like India and China did not have to commit to it. Evaluate this decision.

4 Use the following article to **outline** the key reasons why the Kyoto Protocol wasn't as successful as it should theoretically have been: www.nature.com/news/the-kyoto-protocol-hot-air-1.11882

5 With a partner, or in a group of three, carry out some research on the free rider problem and **outline** what it is. **Describe** how it could come to exist within the context of the Kyoto Protocol.

6 Carry out some research into global greenhouse gas emissions by country. Create a scenario where one of the key contributors (you decide which) decides not to ratify the Kyoto Protocol. Now imagine you are a scientific advisor to that country's government; write a letter with your advice on the decision. **Discuss** how this action could affect the success of the Kyoto Protocol; consider consequences that are indirectly related to global warming as well, making reference to at least two world factors. You could start off by creating a mind map in order to determine the wider implications of specific issues. Extend this discussion to the general success of the implementation of global agreements for air pollution, such as the Convention on Long-Range Transboundary Air Pollution.

7 Submit a bibliography with all of your sources **documented** completely, including citations for the two recommended sources.

◆ Assessment opportunities

- This activity can be assessed using Criterion D: Reflecting on the impacts of science.

Reflection

In this chapter we have **explored** questions relating to the way we might build a better future for all. The story should not end here: we hope that you will take these ideas for making a difference outside the laboratory and into the real world, to begin to build the world you would like to live in as an adult.

Use this table to reflect on your own learning in this chapter					
Questions we asked	Answers we found	Any further questions now?			
Debatable					
Approaches to learning you used in this chapter:	Description – what new skills did you learn?	How well did you master the skills?			
		Novice	Learner	Practitioner	Expert
Learner profile attribute(s)	Reflect on the importance of being principled for your learning in this chapter				
Principled					

Glossary

Note: Words in italics within the glossary definitions are glossary terms themselves.

absolute zero Hypothetical temperature at which atoms have no thermal/kinetic energy, defined as zero Kelvin (0 K)
absorbed To take in a substance or energy through a physical, chemical or energetic process
absorption Action of absorbing (see *absorbed*)
accretions Growth through the gradual addition of material
acid A substance with a pH lower than 7 that produces hydrogen ions when added to water
acid rain Rain that contains dissolved acidic gases and has a pH of less than 5.6
actin A protein present in abundance in muscle cells and in all eukaryotic cells. It links with *myosin* during muscle contraction.
activation energy (E_a) The minimum amount of kinetic energy that reacting particles need to break their bonds and for a chemical reaction to occur
aerobic Requiring or involving oxygen
AIDS Acquired immune deficiency syndrome, caused by infection with the human immunodeficiency virus (*HIV*)
alchemists People who practised alchemy, a medieval chemical science whose goal was to change base metals into gold and discover the elixir of life
alimentary canal The section of the digestive system from the mouth to the anus where food passes
alkane The simplest organic molecules that have the general formula C_nH_{2n+2}. They are saturated *hydrocarbons* which means they contain only carbon and hydrogen atoms and only single *covalent bonds* between the carbon atoms.
allotropes Different structural forms of the same element
alpha particles Ionizing particles released by a nuclear *decay* consisting of two protons and two neutrons
alternating current (AC) Electric current in which the direction of charge flow changes with time
alveoli (singular alveolus) Air sacs in the lungs where *gas exchange* takes place
anabolism The set of chemical reactions by which complex molecules are built up from smaller ones
anaerobic Not requiring or involving oxygen
analogous features Comparable; in evolution, similar in structure but with different evolutionary origin
androids Robots designed to mimic human functions
anemia A condition where the number of red blood cells or *hemoglobin* decreases in the blood
anion A negatively charged ion
anode The positive *electrode* in an *electrolytic cell* where oxidation occurs
antagonistic Pairs of muscles that work together to allow movement to take place; when one muscle contracts, the other relaxes
anther The part in a plant male reproductive system that contains *pollen*
anthropocene Hypothetical geological period during which human activity has significant effect on the Earth's systems
antimatter Matter particles that possess opposite electric charge or different quantum properties to the normally existing particles
anti-neutrino The anti-particle of the neutrino, a *lepton*
aorta The largest artery in the body; it distributes blood from the heart to other arteries
Archaea Single-celled prokaryotic organisms with characteristics that separate them from bacteria
arrhythmia Irregular heart rate
astronomical unit (AU) Mean distance from the centre of the Earth to the centre of the Sun
atomic radius A measure of the size of an atom calculated by halving the distance between the nuclei of two adjacent atoms
ATP (adenosine triphosphate) A high-energy molecule used in *cellular metabolism*
autosomes Chromosomes that are not *sex chromosomes*
Avogadro's constant 6.02×10^{23}; the number of particles found in one *mole* of a substance
axon A long projection from the neuron's cell body that conducts the nerve impulse
background radiation Level of naturally occurring ionizing radiation around us in the environment
bacteria Unicellular prokaryotic organisms that lack membrane-bound *organelles*
bandwidth Range of frequencies of a signal or other source of electromagnetic radiation
baryon A sub-atomic particle with mass that contains three quarks
base A substance with a pH higher than 7 that neutralizes an *acid* to form a salt
base pairs Pairs of the basic units of *DNA* that always pair up together (C–G and A–T)
beta particle/beta radiation Sub-atomic particle with the properties of an electron produced in some radioactive *decay*
Big Bang theory Theory that the Universe began as a single point in space–time before expanding
binomial A system of naming living things using two-part names usually in Latin, the first one for the genus and the second for the species
bioelectrogenesis Generation of electricity by living organisms
bioengineering An area of science where tools and skills from biology are applied using knowledge from engineering to make advancements in science
biomass Organic plant or animal material
bioreactor A vessel in which chemical reactions, which involve organisms or their chemical products, are carried out
bivalents A pair of *homologous chromosomes*
bloodstream Blood circulating around the body
brake horse-power (bhp) Common non-SI unit of power used in machines, especially motor vehicles
breaking or yield point Point of stress at which a material fractures and breaks
Brønsted–Lowry acid A proton (hydrogen ion) donor
Brønsted–Lowry base A proton (hydrogen ion) acceptor
buffer solutions Solutions that resist changes of pH when small amounts of an *acid* or an alkali are added
bundle of His A group of cardiac muscle fibres that conduct electric impulses in the heart from the AV node
calorimetry Experimental technique to measure heat exchange accurately
Calvin cycle Set of chemical reactions that take place in the chloroplast during photosynthesis
cancer Diseases caused by abnormal cell growth that can invade and spread to other parts in the body
cantilever Structural element consisting of a beam or bar, sometimes supported by a brace
capacitor Electronic component that stores charge using a dielectric material
carbon fibre A material that is made from thin filaments of carbon that is extremely

stiff, strong and lightweight so is often used as a strengthening material
carotenoids Organic pigments responsible for yellow, orange and bright red colours in plants
carpel The female plant reproductive system that consists of one or more pistils
cartilage Rubber-like tissue that protects the ends of bones at joints; also present in the ear, nose and other parts of the body
catabolism The set of chemical reactions by which complex molecules are broken down into smaller ones
catalysts Substances that increase the rate of a chemical reaction by providing an alternative pathway with a lower *activation energy* but that remain chemically unchanged
cathode The negative *electrode* in an *electrolytic cell* where reduction occurs
cation A positively charged ion
CCR5 gene A gene that encodes a protein on immune cells. Sometimes it has a *mutation* that is associated with resistance to *HIV.*
cell differentiation The process by which an original cell (mainly stem cell) evolves to a specialized cell
cellular metabolism The set of all chemical reactions taking place in cells
centripetal force Force applied in order to keep an object in circular motion around a point
centromere The part of a chromosome that joins the two chromatids together and to which *spindle fibres* attach during cell division
centrosome An organelle in an animal cell that is made of two centrioles and that produces *spindle fibres* which are required during cell division
cervix A narrow-necked part of the female reproductive system that connects the vagina to the *uterus*
charge-coupled devices (CCDs) Photo-sensitive semiconductor devices for capturing images
chiasma The point of crossing-over during meiosis
chlorophylls A class of green pigments found in plants, algae and cyanobacteria; responsible for photosynthesis
chromatid One of the two copies of a chromosome after its duplication
chromatin Consists of *DNA* wrapped around proteins and packages genetic information into chromosomes
chromosome mutations Chromosome abnormalities that occur during meiosis or are caused by *mutagens*
circuit symbols Standardized symbols used in circuit diagrams
circumference The length of the edge around a circle
clades Groups of organisms believed to be descended from a common ancestor
cladistic classification An approach in which organisms are classified based on shared derived characteristics that can be traced back to a group's most recent common ancestor
clones Cells or organisms with identical genetic material
codons A sequence of three *nucleotides* that correspond to a specific amino acid
coefficient of elasticity In physics, the coefficient relating the stress to the strain, or describing how much a body deforms when a force is applied
coefficients The amount (number of moles) of each substance present
coenzymes Complex organic molecules mostly derived from vitamins that help enzymes to catalyse reactions
cofactors Organic or inorganic molecules that help enzymes catalyse reactions
collision theory A theory used to predict the rates of chemical reactions that states that in order for a chemical reaction to occur, the reactants must collide, have the correct orientation and possess the *activation energy* of the chemical reaction
commutator Mechanism attached to an *AC* generator that alternately makes and breaks current flow so that the output is *DC*
complementary base pairing The process of joining *nucleotides* on nucleic acids to form *base pairs*
complete combustion Combustion that occurs in a plentiful supply of air (oxygen)
compound ion See *polyatomic ion*
compression Change of volume due to pressure, particularly in a gas; a force that tends to squash/compress
concentration The amount of a substance in a given amount of solution
conduct Allow charge to flow through something
consumers Organisms in a *food chain* that feed on other organisms
contracting Changes of tension or length in muscles
control test Experimental measurements to determine the influence on a target dependent variable of factors other than the chosen independent variable
controlled variables Variables that must be controlled in order to determine the effect of an independent variable
cotyledon Part of the *embryo* within the seed of a plant
covalent bond An electrostatic force of attraction between the positively charged nuclei and the negatively charged shared pair of electrons of two non-metal atoms
cracking A process where long-chain organic molecules are broken up into simpler molecules, like short-chain *hydrocarbons*
crops Animal or plant products grown on large scales for commercial use
cross bridges Bridge-like structures caused by the cyclic attachment of *myosin* and *actin* during muscle contraction
crossing-over The process in which non-sister chromatids of *homologous chromosomes* cross over and exchange some parts
cytokinesis The step of cell division when the cytoplasm divides to form two new cells
decays Changes form to another substance, usually of lower mass or energetic state, such as through radioactive *emission*
defecation Elimination of *faeces* from the body via the anus
deficiency Lack of a certain vitamin or nutrient in an organism
deformation Change of shape due to the application of a force (see *coefficient of elasticity*)
denatured A structural change in a protein (usually an enzyme) preventing the *substrate* from fitting into the active site and stopping its activity
dendrites Branched extensions from neurons that connect them to each other
deoxyribonucleic acid (DNA) The nucleic acid that contains the genetic information
depolarization Loss of the natural polarization (difference in charge) between the inside and outside of the plasma membrane of a nerve *axon*
diagnosis The identification of the nature of an illness or a problem by examination of the symptoms
diatomic A substance that consists of two atoms; in a diatomic molecule the two atoms are covalently bonded together
dichotomous key A tool that helps in the identification of an unknown organism. It consists of a series of two choice statements/questions about the characteristics of the organism.
digital electronics Electronic systems that use voltages to represent binary values '1' or '0'; where '1' is usually designated by a voltage between +3.5 V and +5.0 V

dihybrid crosses Crossing two organisms that differ in two traits
diploid A cell that has two sets of all its chromosomes ($2n$)
direct current (DC) Electric current in which charge flows in only one direction
dissociation The splitting up of a substance into ions
diversity Having variation of many different things. In genetics, it means variation of genetic characteristics in species.
DNA sequencing A method or technology leading to the determination of the precise order of *nucleotides* in a piece of *DNA*
domains The highest taxonomic ranks in the three-domain system devised by Carl Woese comprising *Archaea*, *Bacteria* and *Eukarya*
dot-and-cross diagram A diagrammatic representation of the arrangement of the electrons during the formation of an *ionic bond*, which shows the arrangement of the electrons in the reacting elements and in the resulting ionic compound using dots and crosses and the transfer of electrons using curly arrows
Down syndrome A genetic disorder caused by an extra chromosome 21
dynamic equilibrium The position reached by a *reversible* reaction in a closed system when the rate of the forwards reaction is the same as the rate of the backwards reaction
ecological efficiency The description in numbers of how energy is transferred from one *trophic level* to another
effective nuclear charge The difference between the *nuclear charge* (attractive force) and *shielding* (repulsive force)
effectors *Organs* or cells that act in response to *stimuli*
efficiency Ratio of the work done by a process to the energy added to it
egestion The final stage of digestion in which the waste products are removed from the body
ejaculation A liquid discharge of *semen* containing *sperm cells* from the male reproductive system
elastic limit Extension under load beyond which the material will not return to its original dimensions once applied force is removed (see *plastic*)
elastic materials Materials that behave such that the material will return to its original dimensions once applied force is removed
electric circuit Any conducting pathway that allows charge difference to be balanced by current flow
electric dipoles Two regions of space containing opposing electrical charges (positive and negative)
electric potential Potential/energy at a point in space caused by the presence of electric charges
electrical impulse A nerve impulse that carries instructions from one neuron to another by changing the charge between the inside and outside of *axons*
electrocardiogram (ECG) A test that checks the heart rhythm and its electrical activity
electrodes Conductors of electricity through which current enters and leaves an *electrolyte*
electrogenic Producing an electric charge in a living tissue (change in the electrical potential of a cell)
electrolysis The breakdown of an ionic substance called an electrolyte, using an electrical current
electrolyte An ionic compound in solution or in the molten state that is able to conduct electricity
electrolytic cell A type of chemical cell where a chemical reaction creates the flow of electrical energy which brings about a chemical reaction
electromagnetic force Force applied through the application of electrical and/or magnetic fields
electron arrangement A series of numbers, usually separated by commas or colons, that describes how the electrons of an atom are arranged in their shells
electron microscope A type of microscope that uses a beam of electrons to create an image of an object
electron shell diagrams A diagrammatic representation of the *electron arrangement*
electron transport chain A series of complex proteins and organic molecules found in the inner membrane of the mitochondria that transport electrons from donors to acceptors via *redox* reactions and allow the transfer of protons (H^+) across the membrane
electronic configuration See *electron arrangement*
electronic structure See *electron arrangement*
electroplating A process by which a metal object is coated with a layer of another metal through electrolysis
electroreceptors Receptors that enable living organisms to perceive electric *stimuli*
embryo Early developmental stage of a multicellular organism that arises from a fertilized egg and develops to a full living organism
emission Property of releasing energy or mass
empiricism The philosophical idea that knowledge is gained through controlled observation of the physical world
endothermic A chemical reaction in which energy is taken in from the surroundings, usually in the form of heat
energy level diagram A diagram that shows the overall energy change in a chemical reaction
energy levels See *shells*
energy profile diagram See *energy level diagram*
enhanced or anthropogenic greenhouse effect Increased climate warming effect caused by human activity
environmental and ethical impact assessment A systematic analysis of a proposed experiment or process in terms of its likely impact on the environment or ethical consequences
epididymis A tube at the back of the *testes* that stores and carries sperm
equator Imaginary line circumscribing the Earth midway between the poles of rotation; in cell division, the central plane of the spindle in a dividing cell to which chromosomes move during the metaphase of mitosis or meiosis
essential amino acids Nine amino acids which the body is unable to make and has to obtain from food
ethical Relating to moral principles or the rightness or wrongness of an action
Eukaryota Also called Eukarya; a *domain* comprising organisms made up of cells which have membrane-bound *organelles*
eukaryotes Organisms that belong to the domain *Eukaryota* and have cells possessing membrane-bound *organelles* such as a nucleus and a vacuole
extension In physics, an increase in a physical dimension caused by a load force
external fertilization When a male gamete fertilizes a female gamete outside the female body
eyepiece Lens system designed to magnify the image produced by another ('objective') lens system, such as in a *telescope* or microscope
faeces Solid waste remaining from the digestion of food and passed out from a human or an animal through the last part of the large intestine
fauna and flora All the animal and vegetation life in an area
fibres (muscle) Muscle cells

filament In physics, a thin conducting wire; in biology, the part of the male reproductive system in plants that holds up the *anther*
fission In physics, the splitting in two of a nucleus
flow chart Schematic chart showing the possible outcomes of any process
fluorescent microscope A type of optical microscope that uses fluorescence to study a sample
food chain Linear sequence of what eats what in an ecosystem
food web Graphical representation of interconnected *food chains* in an ecosystem to show the complex connections of what eats what in each *trophic level*
fractal Mathematical function in which a property or form repeats at different scales
fractional distillation A separation technique for a mixture of liquids with a difference in boiling points
fractions Groups of chemicals that have similar boiling points and have been separated from a mixture of liquids by *fractional distillation*
freefall Term used to describe the state of 'zero-*g*' on a body in *orbit*
fulcrum A turning point for a *lever*
fullerenes *Allotropes* of carbon that exist as cage-like structures or tubes and that are pure molecules of carbon
function Job or role undertaken by a particular structure in animals or plants
functional group An atom, group of atoms or type of bond that distinguishes the substance from other *homologous series*
gamma radiation Electromagnetic radiation with a shorter wavelength than X-rays produced during nuclear *decay*
gas exchange Process by which oxygen and carbon dioxide are transferred in opposite directions across a specialized surface
gastric juice A fluid made in the stomach comprised mainly of digestive enzymes, hydrochloric acid and mucus
gene mutations Changes in the *DNA* structure of a gene
generator Any device that produces energy; in physics, usually electricity
genetic modification (genetic engineering) Manipulation of genes to result in a desired *phenotype*
genome The total genetic material of an organism
geocentric view The doctrine that held the Earth to be the centre of the Universe
geographic north pole The imaginary point at which the Earth's axis of rotation passes through its surface, defined as North
germline mutations *Mutations* in cells that develop to become gametes and which can be passed to offspring
glands Groups of cells or tissues responsible for making and secreting chemical substances such as hormones into the body of animals
gluten-free Food that has no gluten in it
graphene An *allotrope* of carbon that consists of a single layer of covalently bonded carbon atoms arranged in a hexagonal lattice
gravitation Effect of the force of gravity on masses
greenhouse effect Climate process by which temperature is increased due to the selective *absorption* and re-emission of *infrared* energy by materials
hadron Any sub-atomic particle that comprises quarks or antiquarks (see also *lepton*)
half-equations An equation that shows oxidation or reduction and thus the loss or gain of electrons, respectively
half-life Time taken for half the mass of a radioactive sample to *decay*; alternatively, time taken for the radioactivity of a sample to reduce by half
haploid A cell that has only one set of each of its chromosomes (n)
heliocentric Doctrine that the Sun is the centre of the Universe
hematopoietic stem cells Stem cells that give rise to different specialized cells in the blood
hemoglobin A protein found in red blood cells and mainly responsible for transporting oxygen around the body
HIV Human immunodeficiency virus that infects immune cells and causes *AIDS*
homogenous A mixture which has a uniform appearance and composition
homologous chromosomes A set of comparable chromosomes of the same position and structure, one from the father and one from the mother
homologous features In evolution, structures or features that have evolved from a common ancestor
homologous series A series of compounds with the same functional group and general formula which undergo similar chemical reactions
horse-power (hp) A common, non-SI unit for power frequently used for machines and vehicles
hydrocarbon An organic compound that contains carbon and hydrogen atoms only
hyperpolarization An excess difference in charge in the plasma membrane in a neuron making it more negative
hypothesis A provisional theory about a phenomenon to be tested
imperial system Any (non-SI) system of units derived from the common system used in the British Empire
incineration A method of disposal of waste by burning
incomplete combustion Combustion that occurs in a limited supply of air (oxygen)
induced Caused to occur; in physics, an electric current that is produced through electromagnetic interaction
infrared Region of the electromagnetic spectrum between visible red light and microwave radio, which is produced by or causes thermal vibrations in matter
ingested Consumed
inheritance Passing on genetic information from parents to offspring
inhibitors Of enzymes, molecules that bind to an enzyme and reduce or stop its activity
insoluble A substance (solute) that does not dissolve in a solvent even after mixing
insulated Protected from; in physics, materials which prevent the flow of heat or electricity are called insulators
intensity The amount of energy carried by a field such as electromagnetism
interbreed Reproduce with another species
intermolecular forces Forces of attraction that exist between molecules
internal fertilization When the male gamete fertilizes the female gamete inside the female body
interphase The period between cell divisions when the *DNA* is replicated and *organelles* are produced in preparation for cell division
ionic bond An electrostatic force of attraction between positively and negatively charged ions that have been formed by the transfer of electrons
ionize Process by which an atom becomes electrically charged through the loss or gain of electrons
ionizing radiation All matter or energy emitted by nuclear decay processes that causes ionization in the matter with which it interacts
irreversible A chemical reaction in which reactants react together to produce products, but in which the products cannot revert back to reactants
isometric contraction A muscle contraction that involves tension in the muscle but results in no movement

isotonic contraction A muscle contraction that results in movement
isotopes Atoms of the same element that have the same *proton number* (and thus number of electrons) but a different *mass number* (thus a different number of neutrons)
joints The points where two or more bones meet in animals
kingdoms The second highest taxonomic rank under a *domain*
Krebs cycle Also known as the citric acid cycle, this is a series of chemical reactions occurring in the matrix of the mitochondria that releases energy from carbohydrates, fats and proteins in the presence of oxygen
lacteal The lymphatic vessel in the villus of the small intestine through which fats are absorbed
landfill A method of disposal of waste by burying it underground
lattice A regular arrangement of atoms, ions or molecules in a 3D structure
law of conservation of mass Mass in an isolated system cannot be created or destroyed and can only be transformed from one form to another. This means that in a chemical reaction, the mass of the reactants must be equal to the mass of the products.
Le Chatelier's principle If the conditions of a system in *dynamic equilibrium* are changed, the system will shift in a way to oppose the change and restore the equilibrium
leptons Sub-atomic particles believed to be elementary, i.e. containing no other smaller particles, that are not quarks
levers Structures producing a turning motion about a *fulcrum* when effort force is applied
Lewis (electron dot) structures The arrangement of the outer shell electrons in a covalently bonded molecule
Lewis symbols The arrangement of the outer shell electrons of an atom
Leyden jar A primitive form of *capacitor*
ligaments Dense fibrous structures that hold joints together and connect bones to other bones in the body
light microscope Also called optical microscope; uses light to magnify small objects
light sensors Devices that respond to incident light, usually in the form of a change in electrical property
light year The distance travelled by light in one year
lignin Important component of plant cell walls consisting of complex organic *polymers*
limiting factor Component of an ecosystem that limits the numbers or distribution of a population; in photosynthesis, factors that can affect/limit the speed of photosynthesis when they are in short supply (CO_2 concentration, light intensity, temperature)
lithosphere The part of the Earth that consists of the crust and the upper layer of the mantle
livestock Animals that have become domesticated and raised for agricultural benefits
lock-and-key model The model that describes how substrate and enzyme fit together
locus The position of a gene on a chromosome
London forces Intermolecular forces of attraction that exist between all atoms and molecules. They are the result of the attraction between the slightly positive and slightly negative charges on the atoms or molecules which result from the uneven distribution of electrons. They are also known as instantaneous induced dipole–induced dipole attractions.
lone pairs Non-bonding pairs of electrons
loudspeakers Devices that convert electrical signals into sound waves
lysosomes *Organelles* that contain digestive enzymes and that destroy unwanted things in the cell
magnetic pole The end of a magnetic object from which magnetic field lines can be said to originate
magnification Increase of a property; in optics, the increase in size of an image relative to the size of an object
malaria A disease transmitted through the bite of Anopheles mosquitoes infected with Plasmodium parasites. Malaria causes a range of symptoms and can be lethal.
mass number The number of nucleons (protons and neutrons) in the nucleus of an atom, which represents the mass of an atom; it is also known as the *nucleon number*
measurement uncertainties Uncertainties in the measurement of a dimension introduced by the measuring devices
mechanical advantage Ratio of the effort force to the force produced by a machine, such as a *lever*
mesenteric tissue A tissue that connects organs to each other and to the body
meson A sub-atomic particle with mass that contains two quarks (see also *hadron* and *baryon*)
messenger ribonucleic acid (mRNA) RNA molecules that convey genetic information from the *DNA* to ribosomes in order to be expressed as proteins
metallic bond An electrostatic force of attraction between the positively charged lattice of ions and the negatively charged delocalized electron cloud
metric system System of measurement deriving from the metre, in multiples of 10; more generally, SI units of measurement
microbial electrogenesis The process of generating electricity from microbial organisms
microphone Device that converts incident sound waves into electricity
mitotic index The ratio between the number of cells in a population undergoing mitosis to the total number of cells in a population
mole A counting unit used in chemistry; one mole of a substance contains 6.02×10^{23} atoms/molecules/ions
molecular ion See *polyatomic ion*
monohybrid crosses Crossing two organisms that differ in only one trait
monounsaturated fats Fat molecules that have one unsaturated carbon bond in the molecule
morphological Form and structural features
mutagens Substances that cause *mutations*
mutations Changes in the number or chemical structure of chromosomes or *DNA*
myelin sheath An electrically insulating layer that surrounds *axons* of neurons; it is essential for transmitting the nerve impulse
myofibrils Cylindrical-shaped units that make up muscle cells. They are composed of *myofilaments*.
myofilaments Filaments made up of long chains of proteins (mainly *actin* and *myosin*) and present in muscle cells
myogenic Originating from the muscle tissue itself and not from nerve impulses
myosin A thick protein structure with a tail and a head present in abundance in muscle cells; it links with *actin* during muscle contraction
NADPH Nicotinamide adenine dinucleotide phosphate is a molecule acting as a *cofactor* in anabolic reactions
nanotechnology The study and use of technology that is smaller than 100 nm (nanometres)

native metals Unreactive metals that can be found in nature as pure metals
natural pacemaker The *SA node* starts electrical impulses in the heart inducing heart muscle contractions without the need for nervous stimulation
negligible Something that is so small it is not worth considering and can be deemed insignificant
neuroprosthetic surgery Surgical process in which an artificial limb or other part of the body is connected such that it can be controlled directly by the nervous system
neurotransmitters Chemical messengers which carry the nerve impulse from one neuron to another across a synapse
neutralization A chemical reaction between an *acid* and a *base* that produces a salt and water, where there are no excess hydrogen or hydroxide ions left
nitrogenous bases Nitrogen-containing molecules that make up *nucleotides* which are the building blocks of *DNA* and *RNA* (cytosine, guanine, adenine, thymine and uracil)
nodes of Ranvier Gaps in the *myelin sheath* of an *axon* that help the nerve impulse jump from one node to another
nomenclature A systematic method for naming that scientists use that follows a set of rules
nondisjunction The failure of *homologous chromosomes* or sister chromosomes to separate during meiosis
non-renewable Any source of energy that cannot be replaced once used
normal force, N Force that acts at 90 degrees to a plane
nuclear charge Total charge of all of the protons in the nucleus that results in an attractive force on the oppositely charged electrons of the atom
nucleoid A region in a *prokaryote*'s cytoplasm (not a nucleus) that contains its genetic material
nucleon number Number of nucleons in a nucleus (also known as *mass number*)
nucleosynthesis Process by which elements are formed through nuclear fusion inside a star
nucleotides The building blocks of *DNA* and *RNA*, each made from a sugar–nitrogenous base and a phosphate group
octet rule The tendency of main group elements to bond in a way that results in them having eight electrons in their outer shells, thus achieving a complete shell
ohmic Property of a material in which the change in voltage (*p.d.*) is proportional to the change in current flowing
Olber's paradox Doctrine that the sky should be infinitely bright in an infinite, static Universe
orbits Circular trajectories around a central object; electrons orbit the nucleus in orbitals or *shells*
ores Types of rock that contains sufficient minerals with significant elements like metals that can be extracted
organ A group of tissues that perform a specific function or group of functions
organelles Small, subcellular, membrane-bound structures that perform different functions in the cell
organ system A group of organs that work together to perform specific functions in the body
organic chemistry The study of carbon-containing compounds
oscilloscope Device for displaying changing values of an electrical property in real time
osmosis The movement of water from higher to lower water concentration through a partially permeable membrane
ovum Also called the egg; the female gamete
oxidizing agent A substance that is able to bring about the oxidation of another species, while itself being reduced
palisade cells Oblong-shaped cells towards the surface of a leaf, containing many chloroplasts for photosynthesis
paradigm shift The change in fundamental assumptions that underlie a world view, particularly of frameworks in scientific thought
peer review Process by which the reliability of scientific knowledge is decided through its repeated testing and analysis by other scientists
peptide chains Linear chains of amino acids held together by a peptide bond
periodicity The study of trends and patterns that arise from the arrangement of the elements in the periodic table
peristalsis A series of wave-like contractions along the alimentary canal allowing food to move through the digestive system
perpetual motion machines Hypothetical/imaginary machines that, once started, never cease to move
perturbations Small changes in a property
phenotype The expressed effect of genes
phloem Vessels in the plant that transport cell sap containing the food produced by the plant (sucrose)
photons Light when considered as a particle or a localized 'packet' of wave energy in the quantum physical model
photosystems Protein complexes mainly found in the thylakoid membranes of chloroplasts that are able to use light energy and convert it into *ATP* and *NADPH* thanks to the pigments they contain
photovoltaic solar panels Semiconductor devices that convert (solar) light into electricity
phylogenetics The study of evolutionary origin and relationship between related organisms
physical state Matter can exist in one of three physical states at room temperature: solid, liquid or gas
piezoelectricity Electricity produced by certain materials when placed under physical pressure
pistil Part of the female plant reproductive system that contains the ovary, *style* and *stigma* (also called *carpel*)
pixels Illuminated points on a screen that are used to build an electronic image
plastic Property of a body that maintains deformation when force is applied and does not return to its original shape (see *elastic materials*)
ploidy The number of *homologous chromosomes* in each set of chromosomes in an organism
pollen Male plant gamete
pollutants Substances that when released to the environment have an adverse effect
polyatomic ion A charged particle that is made up of two or more different types of atoms covalently bonded together; also known as a *compound ion*
polymath An individual of wide knowledge in various subject areas
polymer A macromolecule that is made up of many smaller, identical repeat units called monomers
polyploidy When an organism has more than two chromosomes in each set of its chromosomes
polyunsaturated fats Fat molecules that contain more than one unsaturated carbon–carbon bond (double or triple bond)
positron *Antimatter* particle having the same physical and quantum properties as an electron but an opposite, positive charge
postsynaptic neuron The neuron that receives the nerve impulse transmitted from the *presynaptic neuron* through the synapse
potential difference or p.d. The difference in electrical potential between any two points

precipitation reaction A type of displacement reaction where the combination of two *soluble* salts results in the formation of an *insoluble* salt
presynaptic neuron The neuron that sends the nerve impulse to the synapse to be transmitted to the *postsynaptic neuron*
primary data The original data collected from an investigation designed to answer a research question
primary pollutants *Pollutants* that are emitted directly to the environment
principle of conservation of energy Principle that the total energy in a closed system will remain constant; at the most general, that the total energy in the Universe will remain the same
progeny Offspring or organisms resulting from reproduction
Prokaryota *Domain* comprising microscopic organisms without a true nucleus or membrane-bound *organelles*
prokaryotes Organisms that belong to the *domain Prokaryota*
prophase, metaphase, anaphase and telophase Stages of cell division where chromosomes are arranged in distinguished manner until they separate
prostate glands Organs of the male reproductive system that secrete prostate fluid, a component of *semen*
proton number Number of protons in a nucleus (also known as atomic number)
protozoa A diverse group of unicellular eukaryotic organisms possessing animal-like behaviour
pulmonary artery The artery that transfers deoxygenated blood (received from the body) from the heart to the lungs
Purkinje fibres Networks of fibres that receive conductive signals in the heart and induce contractions of the ventricles
radiated Exposed to electromagnetic radiation; transfer of energy without a medium, e.g. through a vacuum in space
radiation Any energy that can be transferred through a vacuum, usually as electromagnetic waves but also as small particles of matter
radiocarbon dating Process by which the age of dead biological material can be determined from the measurement of the emission of radiation by remaining atoms of carbon-14
rate When referring to a chemical reaction it is the change in the concentration of the reactants or products per unit of time
rationalism The belief that reason is the most certain way to form knowledge
ray diagrams Schematic representations of any optical (light) systems
reaction, R A force that directly opposes a motion or effect, but in the opposite direction
redox (reaction) A chemical reaction in which both oxidation and reduction occur
red-shifted Effect of increase in wavelength due to the relative receding motion of an emitter
reducing agent A substance that is able to bring about the reduction of another species, while itself being oxidized
reflection Effect of a surface that causes incident electromagnetic energy to be returned without absorption by the surface; image produced in the surface of a mirror
reflex arc The nerve pathway of a reflex starting from the receptor and ending at the effector
reforming The process where shorter *hydrocarbon* chains can be converted to more stable hydrocarbons with branched chains or rings, using a *catalyst*
relative atomic mass (RAM) The average mass of each element, taking the natural abundance of its *isotopes* into consideration, when compared to the mass of one-twelfth of an atom of the carbon-12 *isotope* (see also *unified atomic mass unit*)
repeated In experiments, successive measurements of an effect on the same variable to establish reliability of the measurement
repolarization Restoring the natural polarization of the membrane of an *axon* after the impulse has passed from one spot to another
reproductive systems Groups of organs that work together to ensure the reproduction of a species
resistivity Resistance per unit volume of a material
resistors Electronic devices designed to have a fixed electrical resistance
resolution The degree of detail that can be reproduced by an image; specifically, the number of *pixels* per unit length in an electronic screen
resolutions In microscopes and images it refers to the clarity of the image
respiration The process by which glucose is broken down to release energy
resting potential The state of normal polarization in neurons where there is no electrical impulse being transmitted
reversible A chemical reaction in which reactants react together to produce products, but the products can react together to revert back to the reactants
right atrium One of the four chambers of the heart; the four chambers comprise two small atria at the top and two large ventricles at the bottom
sampling The process of selecting representative units from a bigger whole
Sankey diagram Schematic diagram showing the conversion of energy from one form to another
sarcomere Basic unit of the muscle limited by two Z lines on each side and composed of *actin* and *myosin*. Repeated sarcomeres make up *myofilaments* and give the muscle its banded appearance under the microscope.
Schwann cells Found in the peripheral nervous system; produce the *myelin sheath* of *axons*
screening See *shielding*
scrotum A pouch of skin that contains the *testes* and keeps them at an optimum temperature for sperm production
secondary data Data collected by others to address different research questions, which are then collated, reorganized and processed to answer a new research question
secondary pollutants *Pollutants* that are not emitted directly to the environment but that are formed as a result of chemical or photochemical reactions of *primary pollutants*
secretory vesicles Vesicles that transport substances that will later be secreted (e.g. hormones) from the site of production to the site of release
segregating In genetics, the separation of alleles when gametes are formed during meiosis
semen A liquid that contains *sperm cells* and other fluids secreted by organs of the male reproductive system
seminal vesicles Secrete a liquid that mixes with sperm and prostate fluid to form *semen*
semi-permeable Only allows certain molecules to pass through
sensory organs Human sense organs that contain receptors to receive information from the environment and convey it the CNS
sex chromosomes Chromosomes that determine the gender of an organism. In humans these are represented by the X and Y chromosomes.
shells The location of electrons within an atom
shielding The repulsive effect between the negatively charged electrons in an atom

sickle cell anemia A disorder caused by abnormally shaped red blood cells which are less efficient in performing their functions which in turn causes many symptoms

single point mutations *Mutations* caused by a change in the *DNA* structure in one single *base pair*

sinoatrial node The SA node is the natural pacemaker of the heart and the site where electrical impulses are generated; see *natural pacemaker*

sister chromatid After chromosome duplication, each chromosome contains two identical sister chromatids

soluble A substance (solute) that dissolves in a solvent

source In plants, the site where nutrients are produced, like the leaf

specialized cells Differentiated cells that can do specific functions

specific power The ratio of power to weight in a vehicle

spectrum A range of values of a property

sperm cells Male sex cells produced by meiosis and matured

sperm ducts Complex tubes in the male reproductive system that transport *sperm cells* from *testes* and transit other organs and eventually transport the *semen* into the *urethra* where it is ejaculated

spindle fibres Fibres produced by centrosomes that are necessary to divide the chromosomes during cell division

spring constant Ratio/coefficient of the force applied to the extension produced in an elastic material

stamen The plant male reproductive system that contains an *anther* and *filament*

standard ambient temperature and pressure (SATP) An ambient temperature of 298.15 K (25 °C) and an absolute pressure of exactly 100 kPa

Standard Model The classification of known and hypothetical matter and *antimatter* particles currently used by physics

state symbols Symbols that are included for each substance in a balanced symbol equation of a chemical reaction that indicate the physical state of the substances involved. They include (s), (l), (g) and (aq).

static equilibrium State of motionless of a system where all internal forces are balanced

stellar nebulae Regions of gas and matter in space where stars are formed through gravitational attraction

stigma Organ of plant female reproductive system that receives the *pollen*

stimuli (plural of stimulus) An event that evokes a reaction in an organ or tissue

strain A stretching force

strong acid An *acid* that completely dissociates or ionizes in solution, shown with a forward-facing arrow

style Part of the female reproductive system in plants that connect the *stigma* where the *pollen* lands to the ovary where it needs to fertilize the *ovum*

substrate The substance that an enzyme works on

supercoils *DNA* twists in many helical turns to make the *DNA* more compact to take less space in the nucleus

superkingdoms Considered as the equivalent of *domains*, superkingdoms are ranked above *kingdoms*

susceptible Likely to be harmed by a particular pathogen

synaptic cleft The space at the synapse where two neurons meet in order to send and receive a nerve impulse in the form of neurotransmitters

synovial fluid A fluid in the cavity of a synovial joint that lubricates the joint and reduces friction between the *cartilage* of the two bones during movement

synthesis A type of chemical reaction where at least two reactants combine to form a more complex product

taxonomy The science that deals with classification of organisms

telescope Optical system that uses at least two lenses to produce a magnified image of a distant object

temperature sensors Any devices that produce a change in property caused by change in temperature, usually as electricity

tendons Strong collagen structures that attach muscles to bones

testes *Organs* of the male reproductive system that produce *sperm cells* and testosterone (a hormone)

tetrads A set of four; in genetics, a set of four chromosomes

theory An explanation for observed phenomena based on general scientific principles

thermal energy Kinetic energy possessed by particles vibrating above absolute zero temperature

thermal expansion Change in bulk properties of a mass due to increased thermal vibration of its constituent particles

tissue A group of cells similar in structure and function that work together to carry out a specific function of an *organ*

transcription The process of producing *mRNA* from *DNA*

translation The process of producing amino acids (eventually proteins) from *mRNA* in ribosomes

transuranic The elements with an atomic number greater than 92, that come after uranium in the periodic table

transverse Oscillation occurring at right angles to the direction of flow of energy

triboelectric effect Property of materials that allows them to hold electrical charge without conducting it

trophic level Level in a *food chain* or a *food web* that is made up of organisms that obtain their energy in a similar way

turgor Force in a plant cell that pushes the cell membrane against the cell wall

UNICEF A world organization working with children in danger

unified atomic mass unit Standardized unit of mass equal to one-twelfth the mass of a carbon-12 atom

unsustainable Any human-produced change that cannot be compensated for or absorbed by natural processes

urethra A tube that connects the bladder to the opening of the body and discards urine; in males, the urethra also carries sperm through the penis to the outside of the body

uterus Muscular *organ* of the female reproductive system where the baby develops during pregnancy

valency The number of bonds that an atom or chemically bonded group of atoms can form

van der Waals' forces A collective term for *London forces* and *dipole–dipole forces*

vector quantity Any quantity possessing both size (magnitude) and direction

ventilation The exchange of air between the lungs and the outside environment

vertebrates A group (sub-phylum) of organisms with backbones

vitamin deficiency A lack of vitamins

volts (V) Measurement of *potential difference* (voltage)

weak acid An *acid* that does not completely dissociate or ionize in solution, shown using a reversible sign

xylem Vessels in plant tissue that transport water from roots to shoots and leaves

yield The amount of product formed in a chemical reaction

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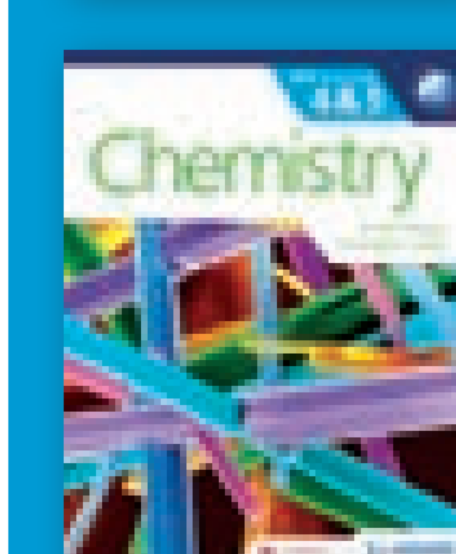

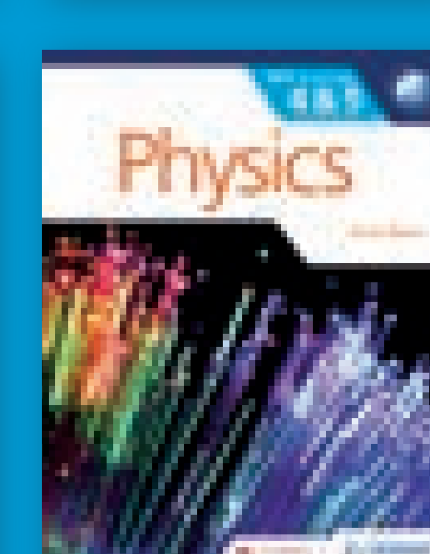

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